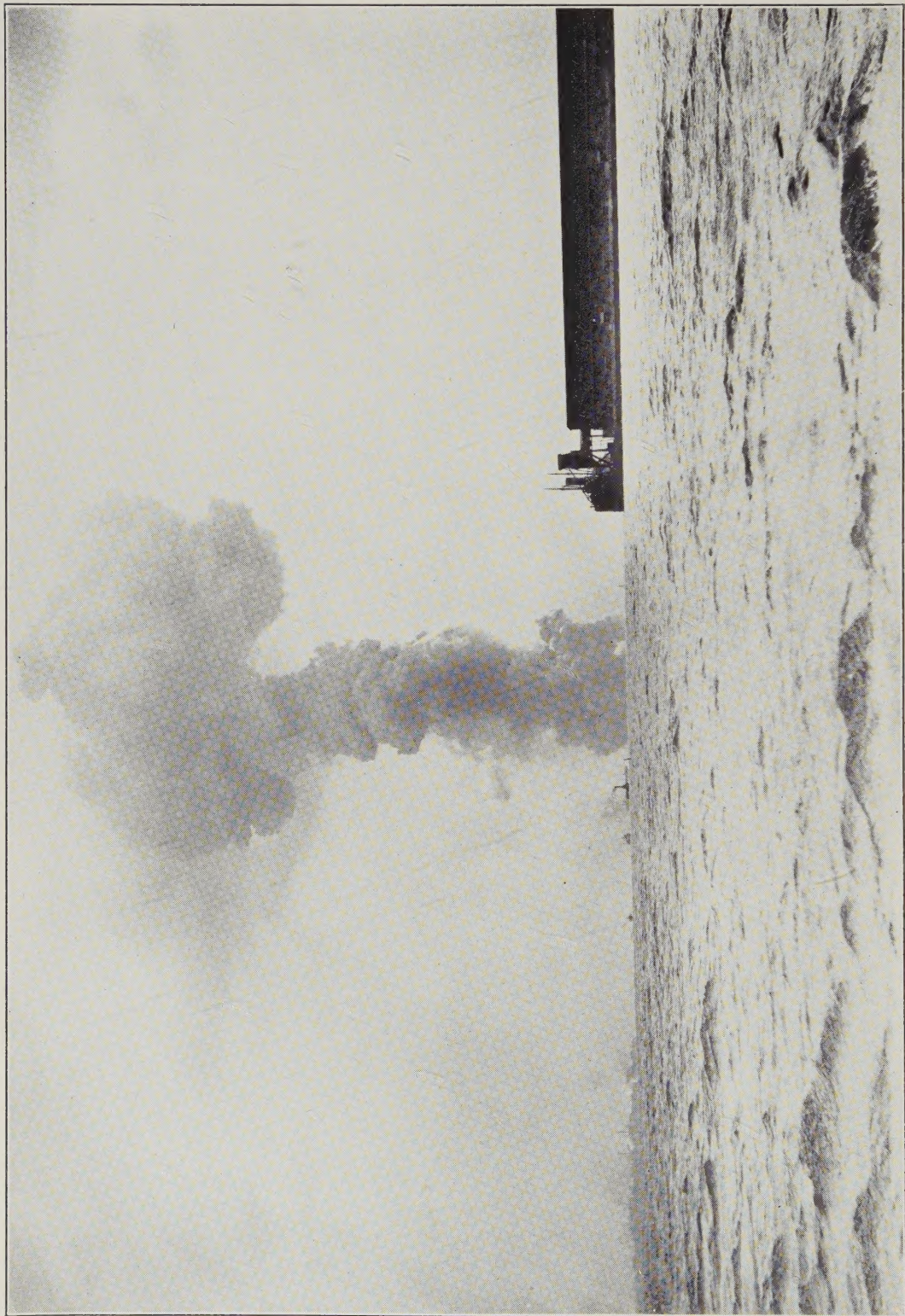


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HISTORY OF EXPLOSIONS
ON WHICH THE
AMERICAN TABLE OF DISTANCES
WAS BASED.



EXPLOSION S.S. "ALUM CHINE"
BALTIMORE, MD., MARCH 7TH, 1913

HISTORY OF EXPLOSIONS

ON WHICH THE AMERICAN TABLE OF DISTANCES
WAS BASED,
INCLUDING OTHER EXPLOSIONS
OF LARGE QUANTITIES OF EXPLOSIVES

COMPILED BY RALPH ASSHETON

PUBLISHED UNDER THE DIRECTION
of the
INSTITUTE OF MAKERS OF EXPLOSIVES

With an introduction
By COLONEL B. W. DUNN, *Chief Inspector*
OF THE
BUREAU FOR THE SAFE TRANSPORTATION OF EXPLOSIVES
AND OTHER DANGEROUS ARTICLES.

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INTRODUCTION

Some years ago a suit for damages resulting from an explosion was being tried. The testimony covered a wide range, including the characteristics of explosives and the effects to be anticipated from explosions. In a casual remark, not for record, the learned Judge said that in such cases he would like to have a qualified and disinterested expert sit on the bench with him. At that time the average mind knew little of explosives and nothing about the probable effects of explosions. The effects can be measured only by recording, studying and applying the experience of others.

In making this study nearly twenty years ago a valuable service to all interested in the subject was performed by the manufacturers of explosives, and this service will be extended materially by the Institute of Makers of Explosives in publishing the facts on which the American Table of Distances was based. These facts will add to the confidence with which that table is accepted and applied.

The table has been incorporated in the laws of a number of States, including California, Kentucky, Massachusetts, Montana, New Jersey, New York, and Ohio, and it has been recommended by the National Fire Protection Association in its code of model ordinances for villages and municipalities. If a court were asked today to enjoin the location of a storage magazine at a given distance from other property and under given conditions this table would be the only guide in predicting the probable effects of an explosion.

It is assumed that the Institute will continue this public service by publishing studies of all important explosions occurring subsequent to those reported herein. For these our data will be more reliable. If the effects are found to be in accordance with the table our confidence in it will be justified. If necessary, minor corrections can be made.

B. W. DUNN.

FOREWORD

Experience has demonstrated beyond a doubt that unless reports and descriptions of explosions are put into some form for permanent record, eventually the data will be lost to the future. Such information has much value, since past experience with explosives and explosions has formed the basis on which protection has been afforded to the public and public property, workmen in the explosives factories, and the property of the manufacturers of explosives. Without such protection explosives which are essential to the progress of the nation in peace time would become a hazard of moment to all concerned and the benefits from their use abnormally restricted.

Practically all civilized nations have, at one time or another, endeavored to reduce to a minimum the risk involved in the manufacture and from the handling and storage of explosives. Each country has taken such measures as seemed fitted to their particular problem.

In June, 1909, Col. B. W. Dunn, Chief Inspector of the Bureau of Explosives, representing the railroads of this country, brought to the attention of the manufacturers of explosives, the necessity of radical changes in the location of magazines used for the storage of explosives, as regards railroads. At the time there were many instances where magazines had been built so close to the railroad as to be considered a hazard to passengers should an explosion occur at the time a train was passing.

A conference resulted in the appointment of a Special Committee by the manufacturers of powder and high explosives. In the beginning, regulations and requirements of foreign countries relative to the storage of explosives were investigated by the Special Committee and were found not to meet the conditions in the United States due to the magnitude of operations. A serious study of the subject was therefore undertaken and there was collected, through various sources, the world's available data relating to the effects of explosions that had occurred. In the years devoted to the study, every possible source of information was carefully searched and a considerable volume of data accumulated covering explosions and the effects therefrom. These statistics covering a period of many years embraced explosions of quantities of explosives, ranging from a very small amount to millions of pounds in manufacture, storage, and transportation, both in this country and abroad.

The work of the Special Committee resulted in the American Table of Distances, specifying protective distances to be maintained between storage magazines for explosives and inhabited buildings, public highways and public railways, which later became the accepted standard in this country.

In the preparation of the American Table of Distances, the facts relating to each separate explosion were thoroughly analyzed from the standpoint of the quantity of explosives involved, conditions under which explosives were stored, the distance at which damage occurred, and the nature of the damage to structures exposed to the force of the explosion. With the factors determined, a chart was plotted and the resulting curve, placed around and outside, embracing the extreme areas of structural damage (with one or two doubtful exceptions) was taken as the distance to be prescribed for protection to inhabited buildings.

In arriving at the distances which should be maintained in the case of railroads, difficulty was encountered due to lack of data on explosions involving passenger trains, but after as careful a consideration as possible, it was concluded that reasonably safe distances from railroads were provided by taking 60 per cent of the inhabited building distances, the reasons for the conclusion being:

The lesser height and small area of railroad cars exposed to concussion, and the greater strength of railroad cars to resist concussion, as compared with buildings.

The fact that while a building is stationary and subject to any risk constantly, the presence of a train is only temporary.

To determine upon distances at which magazines should be located from highways, to reduce to a reasonable limit the danger to persons traveling along the highways should an explosion occur, a large volume of data was accumulated and studied, with the result that over a hundred explosions, involving the experience of about three hundred and fifty persons, were selected as being applicable to this study; of the explosions selected, something like sixty were found to contain accounts of the experiences of one hundred and fifty persons in the open who were subjected to the direct effects of the explosions. To reach a logical conclusion it has been considered that a person on a highway would, in practically every respect, be similar to one in the open; i.e., not exposed to such dangers as collapsing buildings, etc. Under such circumstances, therefore, the resistance of the human body to an explosive wave is the measure of the distance to be required.

To bring this data into concrete form a method similar to that used in establishing distances for inhabited dwellings was followed, to wit:

The various quantities of explosives involved, the distances at which persons in the open were located at the time of the explosion, and their experiences were charted. Based on the plottings, the conclusion was that in the event of an explosion of the contents of a magazine, the distances given in the table of distances are adequate to be maintained between magazines and highways in order to properly protect persons traveling the highway.

After the establishment of the Table of Distances, the accumulation of data relative to explosions was continued, principally in instances where large quantities of explosions were involved.

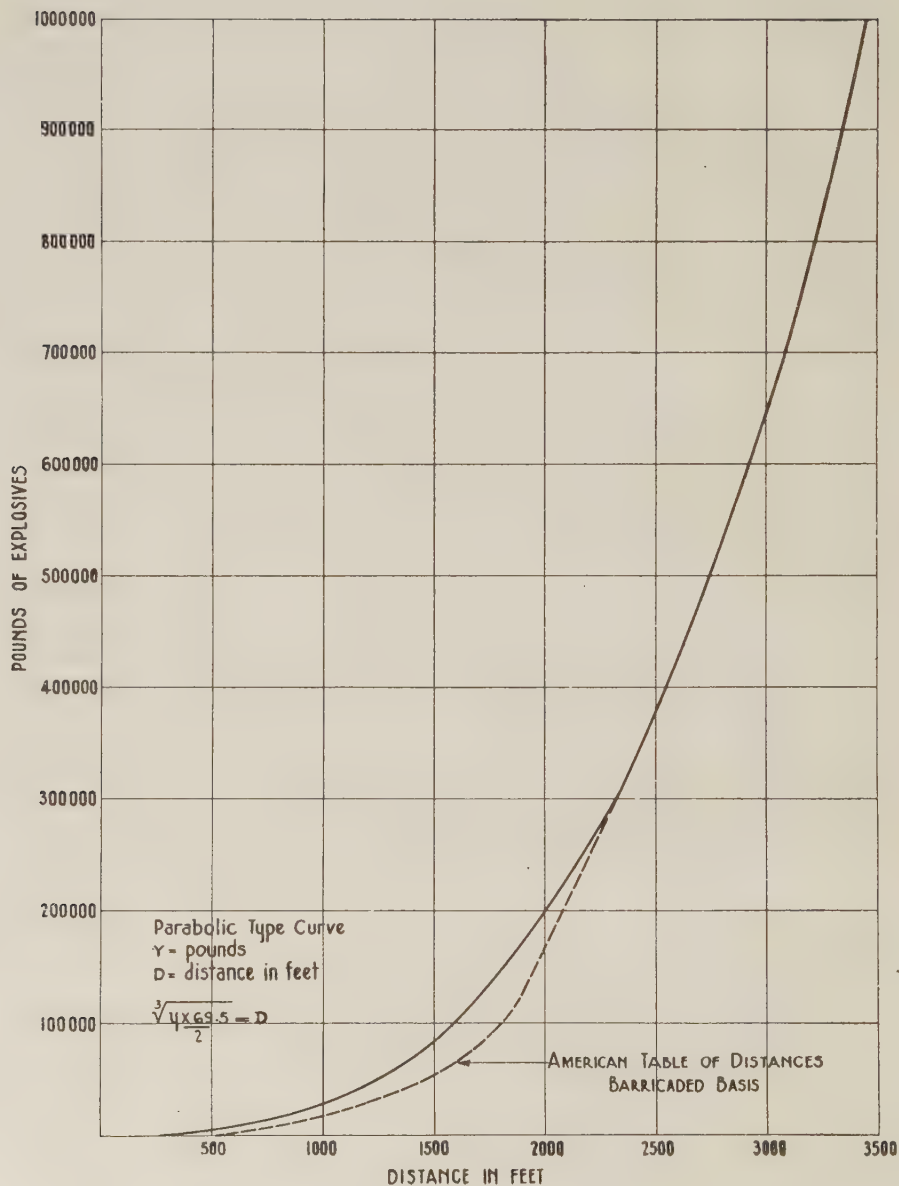
A study of the additional statistics on the effects from explosions confirmed the reasonableness of the distances laid down by the established table, and in no instance indicated that a change or revision was justified.

A parabolic type of curve, which is based on the cube root of the quantity of explosives, is shown on page 20 in comparison with the curve (for inhabited buildings) of the American Table of Distances and it will be noted the two curves conform above 300,000 pounds. Below 300,000 pounds there is a difference between the curves, the greatest variation occurring at about the 100,000 pounds, at which point the parabolic curve is approximately ten per cent less than distances prescribed by the Table of Distances. It can be concluded, however, from the above that the distance to which the appreciable mechanical effects of explosions extend are accordant with the cube root of the charge or weight of the explosives, and the explosion of great quantities of explosives in free air will not produce effects that are destructive or dangerous to buildings except within the radius set forth by the curve. The extension of the American Table of Distances beyond the curve would, therefore, appear to be added protection.

This volume contains accounts of the one hundred and seventeen explosions, involving varying quantities of explosives, on which at the time of the preparation of the American Table of Distances acceptable data had been obtained. The area of structural damage from these explosions formed the basis of the original study.

In addition, there are included accounts of five interesting explosions which were considered, but not tabulated, and descriptions of eighteen other large or important explosions which have occurred since the issuance of the American Table of Distances.

RALPH ASSHETON.



AMERICAN TABLE OF DISTANCES

Blasting and Electric Blasting Caps		Other Explosives		Inhabited Buildings Barricaded*	Public Railway Barricaded*	Public Highway Barricaded*
Number Over	Number Not Over	Pounds Over	Pounds Not Over	[Feet]	[Feet]	[Feet]
1,000	5,000			15	10	5
5,000	10,000			30	20	10
10,000	20,000			60	35	18
20,000	25,000		50	73	45	23
25,000	50,000	50	100	120	70	35
50,000	100,000	100	200	180	110	55
100,000	150,000	200	300	260	155	75
150,000	200,000	300	400	320	190	95
200,000	250,000	400	500	360	215	110
250,000	300,000	500	600	400	240	120
300,000	350,000	600	700	430	260	130
350,000	400,000	700	800	460	275	140
400,000	450,000	800	900	490	295	150
450,000	500,000	900	1,000	510	305	155
500,000	750,000	1,000	1,500	530	320	160
750,000	1,000,000	1,500	2,000	600	360	180
1,000,000	1,500,000	2,000	3,000	650	390	195
1,500,000	2,000,000	3,000	4,000	710	425	210
2,000,000	2,500,000	4,000	5,000	750	450	225
2,500,000	3,000,000	5,000	6,000	780	470	235
3,000,000	3,500,000	6,000	7,000	805	485	245
3,500,000	4,000,000	7,000	8,000	830	500	250
4,000,000	4,500,000	8,000	9,000	850	510	255
4,500,000	5,000,000	9,000	10,000	870	520	260
5,000,000	7,500,000	10,000	15,000	890	535	265
7,500,000	10,000,000	15,000	20,000	975	585	290
10,000,000	12,500,000	20,000	25,000	1,055	635	315
12,500,000	15,000,000	25,000	30,000	1,130	680	340
15,000,000	17,500,000	30,000	35,000	1,205	725	360
17,500,000	20,000,000	35,000	40,000	1,275	765	380
		40,000	45,000	1,340	805	400
		45,000	50,000	1,400	840	420
		50,000	55,000	1,460	875	440
		55,000	60,000	1,515	910	455
		60,000	65,000	1,565	940	470
		65,000	70,000	1,610	970	485
		70,000	75,000	1,655	995	500
		75,000	80,000	1,695	1,020	510
		80,000	85,000	1,730	1,040	520
		85,000	90,000	1,760	1,060	530
		90,000	95,000	1,790	1,075	540
		95,000	100,000	1,815	1,090	545
		100,000	125,000	1,835	1,100	550
		125,000	150,000	1,900	1,140	570
		150,000	175,000	1,965	1,180	590
		175,000	200,000	2,030	1,220	610
		200,000	225,000	2,095	1,260	630
		225,000	250,000	2,155	1,295	650
		250,000	275,000	2,215	1,330	670
		275,000	300,000	2,275	1,365	690
		300,000	325,000	2,335	1,400	705
		325,000	350,000	2,390	1,435	720
		350,000	375,000	2,445	1,470	735
		375,000	400,000	2,500	1,500	750
		400,000	425,000	2,555	1,530	765
		425,000	450,000	2,605	1,560	780
		450,000	475,000	2,655	1,590	795
		475,000	500,000	2,705	1,620	810

*Barricaded, as here used, signifies that the building containing explosives is screened from other buildings, railways, or from highways by either natural or artificial barriers. Where such barriers do not exist, the distances should be doubled.

LIST OF EXPLOSIONS

AREA OF DAMAGE FROM EXPLOSIONS

(See explanatory footnotes)

Chart No.	DESCRIPTION	Quantity of Explosives Involved		Protection Afforded Point of Storage	Distance Structural Damage Occurred	Plotted at	Inhabited Building Distance
		Pounds	Kind		[Feet]	[Feet]	[Feet]
128	Pembrey Burrows, Wales, Mfg.	200	Dynamite	Barricaded	75	75	260
130	Ardeer, Scotland, Mfg.	200	Dynamite	Barricaded	240	240	260
107	Jeanette, Pa., Storage	500	Dynamite		180	90	400
55	Pinole, Cal., Mfg.	500	Gelatin	Barricaded	225	225	400
139	Perranporth, Eng., Mfg.	533	Gelatin	Screened	300	300	410
127	Pembrey Burrows, Wales, Mfg.	600	Nitroglycerin	Barricaded	190	190	430
54	Pinole, Cal., Mfg.	600	Gelatin	Barricaded	300	300	430
143	Uplees Marshes, Eng., Mfg.	650	Nitroglycerin	Barricaded	180	180	445
82	Gibbstown, N. J., Mfg.	700	Dynamite	Barricaded	150	150	460
126	Faversham, Eng., Mfg.	720	Black Powder	Barricaded	75	75	465
133	Upton Towans, Eng., Mfg.	760	Nitroglycerin	Barricaded	216	216	475
135	Upton Towans, Eng., Mfg.	900	Gelatin	Barricaded	150	150	510
48	Landing, N. J., Mfg.	900	Dynamite	Barricaded	275	275	510
74	North Branch, Md., Transp.	950	Dynamite		400	200	520
141	Lower Hope Point, Eng., Mfg.	998	Cordite		150	75	530
143	Uplees Marshes, Eng., Mfg.	1000	Nitroglycerin	Barricaded	192	192	530
109	Robert's Landing, Cal., Mfg.	1000	Nitro-Starch		500	250	530
6	Ashburn, Mo., Mfg.	1080	Nitroglycerin	Ravine & Woods	160	160	530
91	Lewisburg, Ala., Mfg.	1300	Dynamite	Hill	375	375	565
4	Ashburn, Mo., Mfg.	1300	Gelatin	Barricaded	450	450	565
162	Schaghticoke, N. Y., Mfg.	1500	Black Sporting	Barricaded	325	325	600
23	Chattanooga, Tenn., Storage	1500	Dynamite	Woods	425	425	600
77	Plymouth Meeting, Pa., Stor.	1500	Dynamite	Quarry Ledge	600	600	600
47	Landing, N. J., Mfg.	1698	Gun Cotton		125	65	625
5	Ashburn, Mo., Mfg.	1700	Gelatin	Barricaded	220	220	625
124	Chilworth, Eng., Mfg.	2000	Black Powder	Screened	135	135	650
144	Upton Towans, Eng., Mfg.	2000	Nitroglycerin	Barricaded	315	315	755
111	Umbogintwini, Natal, Mfg.	2100	Gelatin		1000	500	705
145	Cliffe, Eng., Mfg.	2100	Nitroglycerin	Barricaded	150	150	650
75	Hazelton, Pa., Storage	2100	Dynamite		400	200	665
12	Beaver Meadow, Pa., Stor.	2250	B. P. & Dyn.	Screened	300	300	665
134	Ardeer, Scotland, Mfg.	2250	Nitroglycerin	Barricaded	600	600	665
168	Gibbstown, N. J., Mfg.	2300	Gelatin	Barricaded	320	320	680
15	Boulder, Colo., Transp.	2300	Dynamite		200	100	675
69	Shenk's Ferry, Pa., Mfg.	2500	Dynamite	Trees	600	600	685
105	Winsted, Conn., Transp.	2500	Black Powder		500	250	685
64	Krummel, Germany, Mfg.	2640	Nitroglycerin	Barricaded	657	657	685
160	Nanaimo, B. C., Mfg.	2793	Gelatin	Barricaded	720	720	700
178	Martin, Pa., Storage	3000	Dynamite		500	250	710
151	Blackbeck, Eng., Mfg.	3460	Black Powder	By location	312	312	730
83	Gibbstown, N. J., Mfg.	3500	Nitro-Starch		700	350	730
138	Ardeer, Scotland, Mfg.	3582	Nitroglycerin	Barricaded	510	510	730
3	Ashburn, Mo., Mfg.	3700	Dynamite	Barricaded	580	580	740
113	Waltham Abbey, Eng., Mfg.	3700	Nitroglycerin	Barricaded	285	285	740
140	Ardeer, Scotland, Mfg.	4000	Nitroglycerin	Barricaded	500	500	750
1	Ishpeming, Mich., Mfg.	4100	Nitroglycerin		1500	750	750

AREA OF DAMAGE FROM EXPLOSIONS—Continued

(See explanatory footnotes)

Chart No.	DESCRIPTION	Quantity of Explosives Involved		Protection Afforded Point of Storage	Distance Structural Damage Occurred	Plotted at	Inhabited Building Distance Barricaded
		Pounds	Kind		[Feet]	[Feet]	[Feet]
170	Ardeer, Scotland, Mfg.	4180	Gelatin	Barricaded	546	546	755
8	Barksdale, Wis., Mfg.	4210	Nitroglycerin	Barricaded	500	500	755
66	Louviers, Colo., Mfg.	4400	Nitroglycerin	Barricaded	625	625	765
148	Pinar del Rio, Cuba, Stor.	4500	Dyn. & B. P.	.....	320	160	765
167	Haskell, Okla., Storage.	4648	Nitroglycerin	Trees	550	550	770
129	Furnace, Scotland, Mfg.	5000	Black Powder	.....	235	118	780
38	Essex, Ont., Transp.	5000	Dynamite	.....	800	400	780
119	Cabot, Pa., Storage.	6000	B. P. & Dyn.	Woods, Brush, ec	350	350	805
68	Marquette, Mich., Mfg.	6080	Dynamite	Barricaded	750	750	805
56	Pinole, Cal., Mfg.	6350	Gelatin	Barricaded	625	625	820
62	Emporium, Pa., Mfg.	6500	Dynamite	Barricaded	600	600	820
172	Hazardsville, Conn., Mfg.	6700	Black Sporting	Barricaded	700	700	845
18	Wilmington, Del., Mfg.	6700	Black Powder	Barricaded	300	300	825
97	Vigorit, Cal., Mfg.	7000	Nitroglycerin	Barricaded	300	300	830
125	Faversham, Eng., Mfg.	7000	Black Powder	.....	900	450	830
9	Barksdale, Wis., Mfg.	7500	Nitroglycerin	Barricaded	700	700	840
131	Hounslow, Eng., Mfg.	7600	Black Powder	Screened	180	180	840
87	Schaghticoke, N. Y., Mfg.	7800	Black Powder	Woods	450	450	850
71	Mt. Carmel, Pa., Storage.	8000	B. P. & Dyn.	.....	600	300	850
120	Herodsfoot, Eng., Mfg.	9000	Black Powder	Barricaded	450	450	870
116	Hull, P. Q., Can., Storage.	9500	"Virite"	.....	400	200	880
7	Barksdale, Wis., Mfg.	9669	Nitroglycerin	Barricaded	850	850	885
112	Pittsburgh, Pa., Mfg.	10000	Dynamite	.....	500	250	890
81	London, Eng., Transp.	10000	Black Powder	By location	600	600	890
52	Beloil, P. Q., Mfg.	12000	Nitroglycerin	.....	1040	520	925
2	Antwerp, Belgium, Storage.	12000	Black Powder	.....	1100	550	925
94	Thompson, Minn., Storage.	12375	Dyn. & B. P.	Hills & Woods	500	500	930
26	Cobalt, Ont., Storage.	12600	Dynamite	Trees	543	543	935
163	Wayne, N. J., Mfg.	12875	Black Powder	.....	1100	550	940
28	City Point, Va., Storage.	16000	Black Powder	Water	495	495	990
90	Steelton, Pa., Transp.	20000	Low Powder	.....	550	275	1055
108	Kellogg, Ill., Mfg.	20000	Black Powder	Barricaded	500	500	1055
115	Holmes Park, Mo., Mfg.	20000	Black Powder	Barricaded	600	600	1055
27	Cle Elum, Wash., Storage.	20050	B. P. & Dyn.	.....	850	425	1055
154	Wilmington, Del., Mfg.	21175	Black Powder	Hills	525	525	1075
173	Tacubaya, Mexico, Transp.	22440	Black Powder	.....	1825	912	1090
179	Jellico, Tenn., Transp.	22500	Dynamite	.....	1000	500	1095
161	San Jose, Costa Rico, Storage.	23120	Dyn. & B. P.	.....	1000	500	1105
96	Vestal Station, N. Y., Transp.	24000	Dynamite	.....	1200	600	1115
106	Yreka, Cal., Storage.	24300	Dynamite	.....	1320	660	1120
165	Communipaw, N. J., Transp.	25000	Dyn. & B. P.	.....	1200	600	1130
44	Fontanet, Ind., Mfg.	25000	Black Powder	.....	600	300	1130
35	Council Bluffs, Iowa, Transp.	25000	Dynamite	.....	1320	660	1130
57	Pinole, Cal., Mfg.	26362	Dynamite	Barricaded	1150	1150	1150
21	Carabanchel, Spain, Storage.	26686	Dyn. & B. P.	In doubt	660	660	1155
164	Cleveland, Ohio, Storage.	26750	Dyn. & B. P.	.....	1700	850	1155
92	Stowmarket, Eng., Storage.	27000	Gun Cotton	.....	1500	750	1160
80	Reddick, Ill., Transp.	30000	Dynamite	.....	1300	650	1205
50	Fort Lyons, Wash., D.C., Stor.	32000	Black Powder	Underground	1050	1050	1235

AREA OF DAMAGE FROM EXPLOSIONS--Continued

(See explanatory footnotes)

Chart No.	DESCRIPTION	Quantity of Explosives Involved		Protection Afforded Point of Storage	Distance Structural Damage Occurred	Plotted at	Inhabited Building Distance
		Pounds	Kind		[Feet]	[Feet]	Barricaded
34	Coolgardie, Aust., Storage.....	34000	Dynamite	In doubt	600	600	1260
49	Forde, Germany, Mfg., (Stor.)..	34950	Gelatin	Barricaded	495	495	1235
33	Connable, Ala., Mfg.....	37500	Black Powder	Hills & Timber	600	600	1305
110	Keeken, Germany, Transp.....	41800	Dynamite	Above Water	3940	1970	1460
70	McAlester, Okla., Storage.....	44950	B. P. & Dyn.	.....	1000	500	1400
67	Lowell, Mass., Storage.....	47775	B. P. & Dyn.	.....	1650	825	1435
20	Bridgeport, Conn., Storage.....	48675	Black Powder	.....	1760	880	1445
59	Jackson, Utah., Transp.....	56000	Gelatin	.....	2640	1320	1460
86	Santander, Spain, Transp.....	66000	Dynamite	Water	1650	1650	1620
117	San Francisco, Cal., Transp....	81750	Dynamite	Water	800	800	1740
37	Erith, Eng., Storage.....	83500	Black Powder	.....	4660	2330	1755
174	San Antonio, Spain, Storage....	103400	Dynamite	Natural	1640	1640	1840
60	Johannsburg, S. A., Storage....	110700	Gelatin	.....	3000	1500	1875
175	Nanaimo, B. C., Transp.....	124530	Dynamite	Water	1100	1100	1900
180	Fairchance, Pa., Storage.....	135000	Dyn. & B. P.	.....	3300	1650	1930
25	Chicago, Ill., Storage.....	162000	B. P. & Dyn.	.....	3000	1500	2020
19	Brescia, Italy, Storage.....	175000	Black Powder	.....	1917	958	2050
176	Vienna, Austria, Storage.....	342190	Smkless & B.P.	.....	4400	2200	2430
58	Highland, Cal., Storage.....	398415	Dyn. & B. P.	Barricaded	2500	2500	2550
85	Rome, Italy, Storage.....	570000	Black Powder	.....	4950	2625	2880
177	Baltimore, Md., Transp.....	600000	Dynamite	Above Water	3200	1600	2935
45	Fontanet, Ind., Storage.....	875000	Black Powder	.....	4000	2000	3325

Manufacture: Explosions occurring in explosive factories.

Transportation: Explosions occurring during transportation—water and rail.

Storage: Explosions occurring during storage.

All distances have been worked out upon the basis of the seat of explosion being barricaded or screened, i.e., when barricaded or screened, the actual distance at which material structural damage occurred has been taken; when not barricaded or screened, the actual distance at which material structural damage occurred has been reduced to one-half. Cases where structural damage came within abnormally short distances have been disregarded when reaching conclusions as to reasonably safe distances.

It will be noted that there are in some instances great variations in the distances at which material structural damage occurs with practically identical quantities of explosives. This is largely due to the fact that in some cases there was an insufficient number of buildings to measure the effect.

PEMBREY BURROWS, WALES

Chart No. 128

On November 17th, 1882, there was an explosion in the nitroglycerin separating house of an explosives factory at Pembrey Burrows, Wales.

The building in which the explosion occurred was of light frame construction, with a felted roof and sand floor, and under ordinary conditions was used for the process of separating acids from nitroglycerin. At the time of the accident, however, the house was being used for thawing dynamite.

The process of thawing consisted in placing the frozen dynamite on rectangular zinc trays about 2 feet long, 1 foot wide, and 2 inches deep, which were fitted inside another zinc tray of sufficient dimensions to allow a clear space of nearly 6 inches all around. This space was filled with hot water. The outer trays were placed on a table, and embedded in the sand which covered the top of the table to a depth of two inches. The workmen were directed to thaw the dynamite by moving it about with their hands in the water heated tray. Any hard lumps of dynamite that were encountered were to be placed in a hot water box of zinc or galvanized iron provided for the purpose. The only implements authorized were two zinc scoops for scooping the frozen dynamite out of the boxes. Not over 200 pounds of dynamite was in the building.

The explosion occurred about noon, and was described as being very violent. Four women employed in the building, and four boys who were carrying dynamite were killed. Five of the seven were killed outright, and the other two were so badly injured that they died in a short time. All of them were in or about the building when the explosion occurred. A man who was about 85 feet away had one arm injured by falling debris.

Although the actual cause of the accident could not be determined, the explosion was known to have originated in the dynamite boxes on the floor.

Structural damage was limited to the building itself, which was cut away to the level of the ground. A wooden building, 75 feet away and screened, sustained no further injury than the breaking of some windows, and one rafter. This was the only building in or out of the factory that sustained any damage whatever.

SUMMARY

Buildings Damaged	Protection	Extent of damage	Feet distant from explosion
Wooden building	Artificial barricade	Windows broken and one rafter	75
Area of structural damage			75 feet
Charted			75 feet
Missiles thrown, up to			300 feet
Glass broken, up to			75 feet

ARDEER, SCOTLAND

Chart No. 130

An explosion occurred in a cartridge hut at an explosives factory at Ardeer, Ayrshire, Scotland, at 8.30 A. M. on May 8th, 1884.

The site on which the factory stood was near the sea. It originally consisted of a number of shifting sandhills about 50 or 60 feet high, well adapted to serve as natural barriers between the buildings. From its isolation the site was eminently suitable for carrying out the manufacture of explosives. But the sand proved objectionable, as it was blown about by the wind, and the danger buildings could not be kept free from grit. In certain of the danger buildings the floors were of sand, which was removed at intervals and fresh sand substituted.

The four cartridge huts which were destroyed by the explosion formed a part of a group of thirteen. The buildings were erected on the sand level at intervals of about 66 feet, and were screened from one another by mounds, instead of natural traverses. By the action of the rain and wind upon the sand, of which the mounds were made, the mounds had diminished in size. They were not of a substantial character; in fact, were quite insufficient to screen effectively one building from another.

The cartridge huts stood at the base of a high sandhill on top of which were the buildings in which nitroglycerin was made.

The huts were rectangular, about 11 by 9 feet inside, of $\frac{5}{8}$ -inch wood planks; sawdust was packed between the planks forming the outer and inner casings. Roofs were of wood, covered with tarred felt. The huts were kept at a temperature of not less than 50° Fah. by means of a steam-pipe passing along the side of the hut opposite the entrance. The steam-pipe was covered at the top with a wooden ledge, and at the sides with wooden battens, to prevent any dynamite from coming in contact with it.

The operation carried on in the huts was the fabrication of dynamite cartridges. The dynamite was mixed and screened in the mixing houses, and was conveyed to the cartridge hut in wooden boxes holding about 200 pounds each. The cartridges were packed with a hand-operated machine which was fastened to the battens on the wall with 3-inch brass screws.

The two runners had just completed the distribution of the second supply of dynamite for the day, and had left not more than two minutes when the explosion in the cartridge hut occurred (at 8.30 A. M.). The four girls working in the hut were killed instantly, and their bodies found in various directions at distances from 100 to 310 feet, the latter distance over the hill on which the nitrating houses stood.

The only dynamite in the building was the second supply of 200 pounds of No. 1 or 75% dynamite. It must have been nearly all in the form of

loose dynamite, as it had only been handed into the hut about ten minutes before the explosion.

The accident was in all probability due to the fracture of a portion of a machine, or the fall of a machine.

The woodwork of the hut was, for the most part, reduced to splinters, which were scattered in all directions up to about 300 feet. One larger piece of one of the uprights was also found about 300 feet away. There was no mark of burning on any of the wooden debris. There was a crater in the sand, about 18 inches deep, where the hut stood.

The structural damage to the adjacent huts was very slight. A hut 66 feet away had the roof lifted off and carried a short distance. The lining of another hut 66 feet away had the battens to which the cartridge machines were attached thrown down. A hut distant 120 feet had windows broken; a hut distant about 135 feet had some glass broken and woodwork shaken; a hut 172 feet away had the door pulled off its hinges, and woodwork shaken, but only one pane of glass broken.

Building	Feet Distant	Extent of Damage
Nitrating house	185	4 small panes of glass broken.
Nitrating house	105	Side blown in a little and 6 windows broken.
Separating house	172	Several boards started, 1 window broken and 10 panes of glass broken.
Washing & Filter house	324	5 small panes of glass broken.
Precipitating house	180	About a dozen boards started, 2 windows and 1 pane of glass broken.
Mixing house	211	1 pane of glass broken.
Mixing house	165	Roof started 2 inches, 1 pane of glass broken.
Cartridge hut	304	Window screen damaged.
Cartridge hut	284	Shelf loose, window screen damaged, steam trap cover damaged.
Cartridge hut	172	Front of hut below window bulged out. Wooden battens loosened. Door torn off hinges. Window screens torn off, and 1 pane of glass broken.
Cartridge hut	112	Woodwork all started and battens hanging loose at one end of hut. Front end of hut below window bulged out. 4 panes of glass broken.
Cartridge hut	172	2 battens loose at one end. Shelf loose, screens damaged and 2 panes of glass broken.
Cartridge hut	224	Shelf loose.
Cartridge hut	290	Shelf loose.
Packing house	240	Roof started. Northeast side thrown inwards 3 or 4 inches. 2 or 3 boards on one side started. One window frame with 14 panes of glass broken.

Upon the explosion of the 200 pounds of dynamite, the dynamite in three other huts—two about 66 feet and one 135 feet away—ignited in-

stantaneously and burned up, setting fire to the huts. The explosion of the dynamite in the huts adjacent to the one in which the explosion occurred, without doubt was effected by cartridges of dynamite, or loose dynamite in or near the cartridge machines projected in a burning state by the explosion.

Six of the ten girls working in the huts in which the dynamite was ignited were burnt to death, being unable to escape from the flames. The other four girls escaped, two from one hut and one from each of the other two, but two were severely burned, and the fourth was injured by the lining of the building and the machine falling on her.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Wooden buildings	Natural sand mounds	Roofs and windows broken, woodwork shaken, see list	240
Area of structural damage.....			240 feet
Charted.....			240 feet
Missiles thrown, up to.....			300 feet
Glass broken, up to.....			324 feet

JEANETTE, PENNSYLVANIA

Chart No. 107

An explosion occurred at Jeanette, Pa., on April 22nd, 1910, at about 6:45 P. M., in a magazine of a firm of contractors at Irwin, doing state road work about a mile from Jeanette.

This magazine was constructed of wooden framing, covered with sheet iron, and the dimensions were 8 x 10 x 8 feet. It was located on the side of a hill, sloping southward about 30 feet from the edge of the bluff and 40 feet from the bottom of the ravine, on the opposite side of which was a sloping hill, rising to a height of about 300 feet. At the point of the explosion the ravine is approximately 400 feet wide.

The magazine was located about 175 feet to 185 feet from the nearest dwelling, and from 250 to 800 feet from five or six other houses, all of which were occupied.

During the afternoon on the day of the explosion, two men had been doing some work on the magazine, repairing the sheet iron which had become loosened by someone trying to break in. This work was completed about 5:40 P. M., and the two men employed went to another part of the works to gather up tools before leaving for the day. They returned and passed the house about 6 o'clock, at which time they saw nothing unusual about the magazine.

A night watchman employed to look after the powder house and equipment came on duty at 6 P. M., and passed the magazine about 6:15 on his way to the boiler room. After a few minutes his attention was called to flames coming from the floor and sides of the magazine. Knowing the nature of explosives in a practical way, this man ran to notify the people living around, and consumed fifteen or twenty minutes in doing this. Two explosions occurred, the first being of a very light nature, possibly the black powder going first, followed by the violent explosion which was no doubt the dynamite. The magazine was on fire about twenty or twenty-five minutes before the explosion.

At the time of the explosion, the atmosphere was said to have been charged with excessive moisture approaching a heavy mist, preceding rain.

Between 400 and 500 pounds of 40% dynamite, a keg of blasting powder, a box of blasting caps, and 500 SS. E. B. caps, were stored in the magazine.

The explosion was caused by fire in the magazine. How the fire originated is not definitely known, but it was thought that the building might have been set on fire maliciously, either by a discharged workman or by agitators involved in the coal miners' strike.

The explosion left a hole in the ground about 12 feet in diameter and 4½ feet deep.

Building	Feet Distant	Extent of Damage
Small frame building	60	Demolished.
Residence	180	Windows and slate roof ruined, porch ceiling shattered.
Residence	350	Windows gone, furniture and sashes broken.

Houses in the bottom of the ravine 1200 feet distant to the southwest had window glass broken. The wave apparently followed a northwesterly course, in a zigzag path. It was claimed that window glass was broken in houses half a mile away.

No one was killed in this explosion. Several people were slightly injured by flying glass.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Wooden buildings	None	Windows and roofs ruined; see list	180
Area of structural damage.....			180 feet
Charted.....			90 feet
Missiles thrown, up to.....			no information
Glass broken, up to.....			3960 feet

PINOLE, CALIFORNIA

Chart No. 55

An explosion occurred at the explosives plant at Pinole, California, on May 1st, 1907.

At this time the pre-gelatinization process was used. Gelatin Mixing House No. 1, in which the explosion occurred, was partly barricaded by an earth bulkhead. 500 pounds of gelatin was involved in this explosion.

The cause of the explosion is unknown.

The structural damage was very slight, the earth bulkhead having successfully protected other portions of the plant. The Gelatin Mixing House No. 2, also barricaded was slightly damaged, and a small 30 calibre mixing house which stood near Gelatin Mixing House No. 1, and the heater house were knocked down.

Two Chinese workmen were killed. No one was injured.

One of the gears of the machine was found about 1200 feet from the site of the explosion. The shafting was forced through Gelatin Mixing House No. 2 bulkhead, probably thrown 250 feet in a direct line. A piece of the paddle was found 100 feet away. Many windows were broken on the plant.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Gelatin mixing house	barricaded	slight	225
Area of structural damage.....			225 feet
Missiles thrown, up to.....			1200 feet
Glass broken, up to.....			no information

PERRANPORTH, CORNWALL

Chart No. 139

An explosion occurred on an explosives factory at Perranporth, Cornwall, England, on January 16th, 1902, at about 11.15 A. M.

A wagon loaded with three wooden tubs, each containing 177 pounds of hand-mixed blasting gelatin, a total of 533 pounds, left the filter house for the purpose of depositing the partly mixed explosives in one of the expense magazines, where in the ordinary course of events it would remain all night to gelatinize prior to machine mixing.

The wagon was coming slowly along with one man hauling on the rope in front and two other men pushing behind. When they came to the switch, they stopped, and the man in front kicked the switch over. Accord-

ing to one witness, the explosion occurred at once. According to another witness only about 40 feet away, the wagon ran off the track when they came to the switch, and the man in front of the wagon lifted the front to replace it on the rails, the explosion taking place immediately after.

From these statements it would appear that the disaster was due either to the concussion of the steel wagon wheels on the tram rails, or to the action of the leading tram pusher in setting the switch with his hob-nailed boots; assuming that some partially gelatinized blasting gelatin had been previously spilt.

The three tram pushers were literally blown to pieces. The man who was pulling the tram was thrown in a direction a little south of west, and his remains were found up to a distance of 750 feet. One of the other two pushers was blown due east, and fragments of his body were found up to a distance of 450 feet, and the third man was thrown southeast to a distance of 750 feet.

The witness who was about 40 feet from the explosion was a laborer in charge of a horse and cart. He was fortunately standing on the far side of his horse. The poor beast fell dead on the spot. The man escaped with a slight wound on his head and a bruised thigh. His hat was torn to pieces and blown to a considerable distance.

A man was standing on the porch of the gelatin mixing house, about 63 feet from the explosion. He also had a miraculous escape, his injuries being limited to a cut on the head and a bruised leg.

The explosion is said to have been heard and felt ten miles from the factory.

If it were not that blasting gelatin is admitted to be the most powerful explosive in general use, the results of the explosion would be somewhat beyond expectations. Notwithstanding the fact that the floor of the wagon on which the tubs rested was 18 inches from the ground, the crater caused by the explosion measured no less than 20 feet long by 15 feet wide by 3 feet deep. Of the wagon nothing was found but a piece of the axle and a plummer block at the bottom of the crater. Several lengths of tram rail were picked up in various parts of the factory, one piece 1050 ft. away.

All the neighboring buildings were more or less damaged according to the distance and to the degree of protection afforded by the mounds.

Building	Feet Distant	Extent of Damage
Final Wash & Filter Hse. (protected by mounds)	249	Practically no damage, only one plank shifted. 1400 pounds nitroglycerin were in here at the time.
Separating House (not screened from wagon)	138	Two sides badly damaged, drawn outwards by the aftersuck. There were between 1300 and 1400 pounds of nitroglycerin here.

Building	Feet Distant	Extent of Damage
Wash Water Tank (protected by mound)	39	Entirely demolished, but the timbers were rotted by acid fumes.
Gelatin Mixing House	63	Side of building nearest explosion practically destroyed.
Temporary Deposit House	150	Built of corrugated iron sheeting. One roofing sheet removed and two side sheets shifted.
Wash Water Tank	165	Hole in roof caused by flying debris.
Foreman's Office (well screened by conformation of ground)	150	Door smashed, some side planks shifted.
Nitrating House (screened by another house)	300	All glass broken, considerable structural damage. A charge of glycerin was in course of nitration at the time. The man in charge of the nitrator was blown through the windows on to the mound outside. The charge was promptly drowned by the foreman. The severe damage to this building was due to its height.
Gelatin Mixing House (screened by mound)	282	Two nearest window frames broken.
Cartridge huts (thoroughly screened)	450 to 480	Door torn off its hinges, bolt twisted and bent; door posts split.

Windows were broken in buildings 450 to 480 feet away. In the chemical laboratory, the glass of the inner door was broken, although completely screened from the explosion by the glass window of the porch, which was not broken.

Outside of the factory area, the damage was limited to glass breakage.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Factory building, frame, tall	Lower part screened, upper part unprotected	Considerable structural damage	300
Area of structural damage			300 feet
Charted			300 feet
Missiles thrown, up to			1050 feet
Glass broken, up to			2100 feet

PEMBREY BURROWS, WALES

Chart No. 127

On November 11th, 1882, there was an explosion in a glycerin nitrating house on an explosives factory at Pembrey Burrows, Wales.

The building in which the accident occurred was of light frame con-

struction. The Boutmy process of manufacturing nitroglycerin was used, and the explosion happened during the process of after separation, which was especially slow with the process in question. Between 500 and 600 pounds of nitroglycerin exploded.

There was no loss of life. The two workmen left the building shortly before the explosion, which happened at about 5 P. M. The only injury done was to another man who was slightly bruised by being thrown against the wall of a building.

The theory was advanced that acid nitroglycerin caused the explosion. One of the workmen said that the fumes were exceptional, and had nearly choked him as he drew off the nitroglycerin just before leaving the house.

Below is a statement of the damage done to other buildings of the factory. The damage was lessened by the mounds screening the nitrating building from the others.

Building	Feet Distant	Extent of Damage
Nitrating house (second)	60	Windows broken, roof much shaken.
Nitroglycerin washing house	60	Shaken and glass broken.
Acid mixing house	80	Glass broken.
Waste acid storage	120	A few boards broken.
Sulphur-glycerin house	190	Windows broken, and iron sheets on roof sprung.
Others	150 to 470	Broken glass.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Frame building	Barricaded	Windows broken and roof sprung	190
Area of structural damage.....			190 feet
Charted.....			190 feet
Missiles thrown, up to.....			no information
Glass broken, up to.....			470 feet

PINOLE, CALIFORNIA

Chart No. 54

An explosion occurred at the explosives plant, Pinole, Cal., on June 4th, 1904, at 9:40 A. M., in a gelatin mixing house, which was artificially barricaded.

In the house at the time of the explosion were the foreman, a machinist, an apprentice machinist, and three Chinese. The hydraulic hoist which was used for lifting the paddles from the bowl of the machine being out of order, had been removed to the machine shop for repairs. It was then sent

back to the gelatin mixing house to be placed against the back wall, as this machine was not fitted with an overhead hoist. The machinist and apprentice boy were engaged in putting the hoist in place at or about the time of the explosion. According to the statement of the apprentice boy, who escaped, he left the building hurriedly because the foreman had been raising and lowering the mixer paddles without the aid of the hydraulic hoist. In one instance it had slipped down rather hard and frightened the boy, so that he refused to stay longer in the house. He claims they were in the act of lowering the paddles for another batch of gelatin and as they were going to proceed as before, he ran out of the building. He had gotten two or three hundred feet away when the explosion occurred.

There were 300 pounds of nitroglycerin in the mixer and 300 pounds in the boxes on the floor outside of the mixer ready for another charge. In all about 600 pounds exploded.

The cause was not definitely known, but it was thought to have been mechanical. The stirrer shafts probably dropped, striking the bottom of the mixer containing a charge of nitroglycerin.

When the explosion occurred, a sheet of flame shot up at least 200 feet into the air, scattering burning debris which started several grass fires. These fires menaced and eventually would have destroyed the house used for the storing of nitroglycerin and guncotton, which was located about 300 feet from the scene of the explosion. This house, which was barricaded, was considerably shattered. There was 1650 pounds of nitroglycerin in copper buckets in this house at the time of the explosion.

The Champion Mixing House fired, and almost immediately the dope contained therein was consumed by flames.

About 45 minutes or an hour after the explosion, the ice house and tank took fire. This was started by firebrands thrown across the flat, which set fire to the grass near the boxes covering the brine line from the ammonia compressor house to the nitroglycerin house, and the burning grass carried the fire to the building itself and the timbers supporting the two tanks.

There were five men killed; the foreman of the gelatin department and a machinist, and three Chinese. All were in the house at the time of the explosion. One man was injured by a falling timber while fighting the fires.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Nitroglycerin store-house	Barricaded	Considerably shattered	300
Area of structural damage			300 feet
Charted			300 feet
Missiles thrown, up to			not determined
Glass broken, up to			not determined

UPLEE'S MARSHES, FAVERSHAM, ENGLAND

Chart No. 142

An explosion occurred at the explosives factory at Uplees Marshes, Faversham, England, on August 23rd, 1903, at 3:35 P. M.

The accident occurred in the final nitroglycerin wash or filter house. The building was lightly constructed of wood on a brickwork foundation, with "sleeper walls" supporting the floor. This floor was of lead sheeting on tongued planks with felt between, the lead being turned up for several inches all around. The roof was of wood covered with felt.

The building was surrounded by a mound at a distance of a few feet. This mound was revetted on both sides by means of wooden standards and planks, and was unfortunately composed of all sorts of rubbish, such as earthenware, plates, glass bottles, tin utensils, and lumps of old iron, which added materially to the difficulty of identifying any contents of the building.

At 1:40 P. M. on Saturday, the foreman had locked up the final washing house, after seeing that everything was cleared up and that the filter tank was properly covered. From this tank 7 charges of $49\frac{1}{2}$ pounds each had been drawn off during the morning for the manufacture of cordite, leaving about 650 pounds of nitroglycerin remaining from the batch of 1000 pounds which had come down from the separating house. At 3:35 on Sunday afternoon this nitroglycerin exploded.

It is probable that this explosion was due to spontaneous ignition. This explanation seemed almost inconceivable, as there was supposed to be no explosive in the building except that which was contained in the filter tank, which had been thoroughly purified, and in fact partly used for cordite. Later it became known, however, that there was a small filter in the building in addition to the main apparatus, and that this small filter was used for the purpose of extracting the nitroglycerin from the salt and flannels used in the larger vessel, and from "mud" collected from the washing water. At the time the explosion occurred, there was some mud on the flannel of this small filter, and the two or three pounds of nitroglycerin that had been extracted from the mud was still in the tank. In exact correspondence with the position of this small filter a small crater was found, about 6 feet x 3 feet x 2 feet deep, bearing indications that it had been formed prior to the larger one. Pieces of the floor, for instance, were lying at the bottom of it under the clay thrown up by the main explosion.

Under these circumstances, there was no hesitation in attributing this accident to the spontaneous decomposition and consequent ignition of the mud on the flannel of the small filter, followed by the explosion of the few pounds of nitroglycerin in the tank, which in turn communicated the ex-

plosion to the larger filter. This mud consisted for the most part of lime and carbonate of lime, precipitated when the strong solution of soda ash came in contact with well-water; and also contained no doubt such small particles of nitroglycerin as may have been entangled in it during the process of filtration, and which the subsequent washing in the smaller filter had failed to remove.

Even though it was impossible to point to the precise cause of the spontaneous ignition of the nitroglycerin on the filter cloth, it was most probable that the explosion was due to such spontaneous ignition in the small filter.

Occurring as it did on Sunday afternoon, the explosion was happily unaccompanied by personal injury, but the damage to property was considerable.

The filter house was of course entirely demolished, leaving in its place a circular crater 20 feet across and 6 feet deep. Even of the mound mere traces only were left.

The nitrating house at a distance of 129 feet, and protected by a substantial mound of earth revetted on each side with timber, was practically wrecked.

The other two final washing houses were both severely shaken. One at a distance of 180 feet, containing about 25 pounds of nitroglycerin in the filter tank escaped, with the loss of a few planks, but the other, 99 feet away from the site of the explosion, was badly bombarded with lumps of clay from the mound around the filter house that exploded, the door being knocked off its hinges and a large hole being driven through the roof, in addition to general displacement of planking. Fortunately the nitroglycerin in the filter, amounting to no less than 1000 pounds, was not fired. Boatmen on the river had an anxious time with the falling debris, but no actual damage was done outside the factory area. A building 99 feet distant from the explosion was bombarded with lumps of clay from the mound.

A large number of window sashes and glass were broken throughout the factory.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Washing house (frame)	Barricaded	Planking displaced	180
Area of structural damage			180 feet
Charted			180 feet
Missiles thrown, up to			no record
Glass broken, up to			no record

GIBBSTOWN, NEW JERSEY

Chart No. 82

An explosion occurred at the explosives works, Gibbstown, New Jersey, on June 23rd, 1903, at 11:56 A. M.

The accident happened in a dynamite mixing house, protected by an artificial barricade.

The mixing tubs were practically new, having been installed and operated for the first time on June 18th. After their installation, they had been carefully examined every day, and were working satisfactorily. The plows were set most carefully, so that there would be no friction between the plow and the side of the tub. When the powder was placed in the tub, the wheels were raised slightly, which would make them clear the rubber scraper. The scrapers were made of pure soft rubber, $\frac{1}{2}$ -inch thick.

The mixing of 40% dynamite, amounting to about 700 pounds, had been running for about five or six minutes when the powder fired.

There were seven men in the house; as soon as the alarm was given, all of them attempted to make their escape. One man was fatally injured and died from burns thirty minutes after the explosion. The others all escaped, some of them reaching a distance of 420 feet from the building by the time the explosion occurred.

The cause of the accident was not known. It was said afterwards that while the powder was mixing, the smell of burning rubber was noticed in the house. One of the employees had spoken of it, and had looked at the driving belt in the annex to the mixing house, found that it was all right, and had then examined the plows and mixing wheels while the powder was being mixed. These were found to be cool and all right, but a short time afterwards the powder blazed up, the men stated, all over the tub.

There was no great damage to other buildings on the factory. The water tower located about 150 feet from the building had considerable weather boarding blown off above the line of the mixing house barricade. The Hall Machine House, 275 feet away, had several sashes broken, as had also the hand punching house, 375 feet away.

The door of the nitroglycerin house, 775 feet distant, was dislodged from the track on which it ran. The force of the explosion was not felt to any extent on any other portion of the factory.

The barricades around the building were practically intact. The heavier timber which had been used in the construction of the building seemed to have been shot up in the air, and descended on all sides of the barricade within a radius of 100 feet.

Some few of the lighter pieces of debris were carried a distance of 300 to 400 feet. Glass was broken up to 725 feet.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Water tower	Barricaded	Boards blown off above line of barricade	150
Area of structural damage			150 feet
Charted			150 feet
Missiles thrown, up to			400 feet
Glass broken, up to			725 feet

FAVERSHAM, ENGLAND

Chart No. 126

On December 11th, 1880, at 3 o'clock A. M., there was an explosion in a glaze house on a powder factory at Faversham, England.

The building in which the accident happened was being used exclusively for experimental glazing in a glaze tub of exceptional construction. The remarkable thing about the explosion was that at the time that it occurred the machinery was not in motion, and had not been in motion for 12 hours previously, during which time all manufacturing had been suspended, and the building itself locked up.

The experimental glazing house was a low, one-storied building, 18 x 16 feet, with a slated, wood-lined roof, and lit by two skylights. On the northeast side of the building was a sort of verandah, or boatshed, over a small water-course, by which all removals of powder to and from the building could be made. There was a door at the southeast side of the building, but no other openings.

The contents of the glaze tub which exploded amounted to 720 pounds of finished powder.

The house was completely destroyed, the boards and debris being projected in different directions. The site of the building after the explosion was marked only by a crater full of water, and by broken timbers and other remains.

The boiler house, distant only 75 feet, but screened by huge traverses, sustained no serious structural damage. The roof was disturbed and apparently had been raised and slightly drawn towards the explosion. A few rafters were displaced, but none were broken. Several of the slates and some of the lead on the roof were stripped. The engine house, which adjoined or formed a part of the boiler house, had windows back and front broken, but the injury was almost entirely confined to breaking glass. Neither the boiler or engine houses had the walls or main structure in any way affected.

The wooden glazing house, distant only about 200 feet, but screened

by double traverses and the engine and boiler houses, was uninjured, except that some of the windows had the glass broken, and the door towards the explosion drawn outwards. The slates on the roof were intact.

In the opposite direction, the nearest building was the corning house, distant 210 feet, with two large intervening traverses. This building had a few slates stripped and disturbed, and some of the wooden planks of the building drawn outwards. One only of five windows facing the explosion was broken.

The above covers the damage of any description inside and outside of the factory.

The explosion was unattended by any loss of life or personal injury.

The cause of the explosion was not determined, but the theory was advanced that it was the work of some malicious and evil-disposed person. However, it was more likely to have been the result of overheating the glazed charge of powder.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Boiler house	Completely barricaded	Roof disturbed and rafters displaced	75
Area of structural damage.....			75 feet
Charted.....			75 feet
Missiles thrown, up to.....			no record
Glass broken, up to.....			no record

UPTON TOWANS, CORNWALL

Chart No. 133

On September 4, 1894, an explosion took place in a gelatin mixing house at Upton Towans, Cornwall, England.

The mixing house in which the explosion occurred was constructed with walls of wood, in two thicknesses, with a layer of "breeze" between them, and the roof was of wood, felted over externally. It had a close-joined wooden floor, and the interior, except the floor, was varnished. Outside the building at one end there was an annex containing a small steam-engine for driving a mixing machine, and beyond the annex a raised platform about the level of the eaves of the building, on which stood a large tub or cistern full of water, with an arrangement for heating it by the injection of steam. The steam for the engine and heating the water in the cistern was obtained from a boiler house outside the danger area, and distant some 1500 feet. The building contained, in addition to the mixing machine, five leaden troughs set in a framework of wood. These were used for the pre-

imentary mixing of the explosive by hand, before it was treated in the mixing machine. The troughs, as well as the mixing machine, were surrounded by jackets through which a continuous flow of hot water from the cistern could be kept up, the water being carried off into a drain by a $\frac{5}{8}$ -inch pipe, while an inlet pipe with a buoy cock kept the cistern full.

The building was surrounded, except at one corner and in front of the doorway, by a substantial mound of sand, faced with turf, as high as the top of the roof.

The leaden tanks, five in number, were rectangular, 3 feet, 9 inches long; 1 foot, 9 inches wide; and 1 foot, 5 inches deep. The mixing machine was similar to those used for kneading bread. The interior was of brass and contained two axles, each fitted with four arms or paddles, also of brass, set in a helix, which revolved in opposite directions, one at half the speed of the other.

The explosive in course of manufacture was 131° Fahr. in the tanks, and 122° Fahr. in the mixing machine.

At the time of the explosion a variety of gelatin dynamite No. 2, known as gelignite, was being made.

In making this explosive a charge, consisting of 130 pounds of nitroglycerin and nitro-cotton, in the proper proportions, was stirred for a period varying from two to four hours in the leaden tub with a wooden spud. It was then transferred in small portions at a time on the spud to the machine, which was kept running, and there it remained until the workmen judged by eye that the nitroglycerin was thoroughly combined with the nitro-cotton. This operation occupied a few minutes only, or extended even to an hour. The absorbing ingredients, nitrate of potassium and wood meal, were then added, and, after a further period in the machine, the process was completed.

The mixed nitroglycerin and nitro-cotton was being transferred from a lead tank to the mixing machine at the time of the explosion.

The amount of explosive in the building was 290 pounds of partly mixed nitroglycerin and nitro-cotton in three tanks; 130 pounds of the same partly in one of the tanks and partly in the mixing machine; 120 pounds of nitroglycerin in one of the tanks, and a similar amount in buckets on the floor; or 760 pounds in all.

The two operatives were killed instantly, the body of one was scattered in fragments, and the other dismembered, portions being found 381 feet from the mixing house.

The building, annex and platform were blown to pieces. Parts of the machinery and debris generally were projected in all directions.

Structural damage to other buildings was of the slightest possible character, doubtless due to the excellence of the mounds by which the

buildings generally were surrounded. The damage consisted for the most part of displaced boarding.

Pieces of metal from the machinery were projected over other buildings, some even to a distance of 600 feet and upwards.

As to broken windows, 1071 panes of glass were broken on the factory property.

No structural damage whatever was done to other property. Two panes of glass were broken outside the works at distances respectively of 1500 and 3300 feet. The sound was heard 20 miles distant.

There was no evidence to show definitely what was the cause of this explosion.

The effect on the nearby buildings was as shown below:

Building	Feet Distant	Extent of Damage
Separating water	180	Inside boarding displaced and principals of roof cracked. Door, sash and glass broken,
Separator	156	No damage.
Safety tank	276	Inside boarding much displaced. Few panes of glass broken.
Deposit of washings	165	Inside and outside boarding displaced considerably, and roof lifted. Glass broken.
Wash and filter house	250	Inside boarding slightly displaced. Few panes of glass broken.
Office and laboratory	216	Inside boarding displaced and roof lifted. Sash and glass broken.
Packing house	230	Inside boarding displaced. Glass broken.
Detonator magazine	180	Door lock forced open, ceiling down. Some slates blown off.
Laboratory magazine	288	No damage.
Cartridge huts (8)	363 to 390	Glass broken.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Office & laboratory	Completely protected	Inside boarding displaced, roof displaced	216
Area of structural damage.....			216 feet
Charted.....			216 feet
Missiles thrown, up to.....			600 feet
Glass broken, up to.....			1500 feet

UPTON TOWANS, CORNWALL

Chart No. 135

An explosion occurred on an explosives factory at Upton Towans, Cornwall, October 19th, 1899, at 4:06 P. M.

The explosion occurred in the gelatin mixing house. It was barricaded

by artificial mounds.

The operation which was in progress at the time of the accident was that of "mixing nitro-glycerin and ingredients to form blasting gelatin," generally considered the most powerful of known explosives. It consisted of nitroglycerin converted into a stiff jelly-like substance by dissolving in it a small percentage of the soluble variety of nitro-cotton, technically known as "collodion cotton" though the particular variety used for this purpose was more highly nitrated than that used for the manufacture of collodion.

The operation of mixing was carried out as follows: A weighed quantity of dry nitro-cotton was placed in a lined box and taken to the filter house, where the required quantity of nitroglycerin was run in upon it, and the two ingredients were slightly worked by hand until the nitroglycerin was taken up by the nitro-cotton, and was no longer free to run as a liquid. The box was then removed to one of the mixing houses, and there emptied into one of the lead-lined and water-heated tanks, termed jelling tanks. These tanks were jacketted with hot water, and in them the material was allowed to remain for some hours to complete the gelatinization. Finally, the charge was placed in a mixing machine, also water-heated, and worked for about one hour, after which it was ready for removal to the cartridge huts to be made into cartridges of the required weight and diameter.

During the period in which the charge remained in the jelling tank, it was turned over once every half-hour, in order to bring the upper and colder side into contact with the water-heated bottom of the tank. This was done by cutting the mass into sections with a wooden spud, and turning each section in succession. Meanwhile, the temperature was observed by one thermometer in the water flowing into the jacket, and by another thrust about half way down into the mass of the explosive. The latter temperature was never allowed to exceed 122° Fahr., whilst the temperature of the water was not permitted to exceed 158° Fahr.

On the afternoon of October 19th work was proceeding as usual. Each of the jelling tanks contained a charge of 150 pounds of blasting gelatin, making a total of 900 pounds of explosive present. Two men were working in the building, while a boy was in the annex attending to the small steam-engine which drives the mixing machine. The machine was emptied at about 4 P. M. and the finished charge was sent to the cartridge huts. The two men proceeded to clean the machine while the engine was still running, one occupying himself with the interior, while the other cleaned the bearings. By about 4:04 P. M. the first man had finished his portion of the work, and at about the same time the second man called the boy to stop the engine, which order was at once obeyed. The second man continued to clean the bearings, while the first one proceeded to "turn the jellies."

For this purpose he removed the two covers of one tank, and commenced to make a cut in the blasting gelatin in the direction of the end of the building by holding the spud left handed and driving it through the mass in that direction. In so doing the corner of the spud would rub along the bottom of the tank. On withdrawing the spud he saw a little blue smoke ascend, and, as he describes it, noticed the blasting gelatin begin to spit. He called out to the other man to run, and he himself ran through the open door and took shelter behind the protecting mound. The second man, on hearing the cry, turned and saw flames beginning to ascend from the tank. Thereupon he made good his escape through the service window, and, scaling the mound, fell or was thrown down over the end, his clothing having meanwhile been set on fire.

The first man said that after reaching a place of safety, he looked up and saw intense flames reaching over the mound and appearing to be "coming right down on him." Immediately after a violent explosion occurred. He remained absolutely uninjured. The second man picked himself up and ran until met by another man, who extinguished the fire in his clothing. He sustained somewhat severe burns, but no other injury. The whole time between the first ignition and the explosion cannot have exceeded four seconds.

The boy meanwhile had remained in the boiler room and was killed instantly. The doors, both of his compartment and the mixing room were open, and he could not have failed to hear the man call out a warning; yet he appears to have made no attempt whatever to escape. Whether he was paralyzed with fear, or whether, not being able at once to see the danger, he hesitated a moment, and then saw that his escape was cut off by flames issuing from the door of the mixing room, it would be impossible to say.

The two men were steady experienced workers. The evidence given by them was so clear and straightforward, and so entirely concordant, that there was not the slightest doubt that the accident originated in exactly the manner they described. There is direct and reliable evidence that the explosion started in one of the mixing tanks. The primary cause was undoubtedly friction between the wooden spud and the lead floor of the tank, but where an ignition takes place at a single point at the bottom of a mass there would inevitably be some very slight delay before the occurrence is observed.

It is probable that a fragment of foreign matter, such as earthenware from the nitrating pots, or of cinder refuse from the lining of the building which had found its way into the explosive, or else that a knot of nitro-cotton which had escaped gelatinization, came between the edge of the spud and the bottom of the tank. The extra friction thereby induced, together with the elevated temperature of the blasting gelatin, would be

quite sufficient to produce ignition, and to this combination of conditions the accident was most probably due.

The explosion was a violent one. The building was completely demolished, and a crater formed in the sand which extended over the whole of the side previously occupied by the mixing tanks, reaching a depth of two feet immediately under the tanks. Here the sand was pulverized and caked, presenting a peculiar white appearance, which is only seen in the case of the detonation of a so-called high explosive. A portion of the floor of the end of the building occupied by the mixing machine remained intact, and the machine itself was found standing in place and only slightly damaged. The engine was thrown down and smashed. Substantial mounds surrounding the building stood well and were only slightly damaged.

The explosion was confined to the building in which it originated, and no other building was completely wrecked; but all those in the immediate vicinity, being of very light construction, suffered more or less structural damage. The two which sustained the most damage were another mixing house and the laboratory, neither of which was surrounded by a mound. These buildings were about 150 feet away from the house in which the explosion occurred. In the case of the mixing house, all the roof trusses were either broken or cracked, and the roof itself was lifted about 3 inches on one side.

In the laboratory the roof was lifted about 2 inches and displaced, so that the roof trusses were slightly twisted. The inner lining was blown in on one side, allowing the cinders between the walls to escape. On the opposite side part of the outer planking was displaced. Window sashes were broken or damaged. The interior of this building presented a scene of the utmost confusion. Nearly every movable article inside had been broken or displaced; the whole of the floor was strewn with window glass and fragments of bottles and apparatus.

Other buildings in the vicinity sustained damage of a less serious character. Beyond a distance of 240 feet, the structure of the buildings did not appear to suffer.

The amount of heavy debris projected was small, and no pieces of any weight were thrown to a greater distance than 120 or 150 feet. Light fragments, however, were found at distances up to 1500 feet on the leeward side, a strong wind having been blowing at the time. Numerous windows were broken throughout almost the whole factory.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Mixing house and laboratory	Artificial barricade	Roofs damaged and displaced. Planking displaced	150

Area of structural damage.....	150 feet
Charted.....	150 feet
Missiles thrown, up to.....	1500 feet
Glass broken, up to.....	No record

LANDING, NEW JERSEY

Chart No. 48

An explosion occurred at the explosives works, Landing, New Jersey, on January 20th, 1909, at 1:25 P. M.

The accident happened in the Quinan packing machine building. About 900 pounds of dynamite, some of which had not yet been packed, was in the building at the time.

The powder foreman had been in the house just five minutes before the explosion, and found everything in good condition. The hopper had just been filled with powder, and all the men were working in their proper places, one man running the machine, with a helper, one man putting shells into shuttles, and a fourth man hand packing. No complaint had been made either to the powder foreman, or to the assistant superintendent, who had also visited the house that morning.

The cause of the accident is not definitely known. The following theories have been advanced:

When the stirring box was nearly empty of powder, the man running the machine used a soft pine stick, which was run across the loading tamps so as to knock down any powder which may have bridged above the tamps. This was generally done when the machine was at rest, although at times the men did this when the machine was running. Should, for any reason, the stick in the man's hand have slipped off and been caught between the stirrers and the tamps, it could have caused the fracture of the stick and perhaps an explosion. Or, for some reason or other, it might have been that the hand-packer had his punching stick wedged in the funnel, and in trying to remove it have caused sufficient friction to start an explosion.

The four men in the building were instantly killed, and seven other men on the plant were injured, but not seriously, at distances of from 175 to 450 feet.

The Quinan machine house was totally destroyed, and the structural damage to the rest of the plant was as follows: A brick magazine 275 feet away from the explosion had five rows of bricks dislodged, and a wall bulged out. The gelatin paper store, 150 feet away, had the side stove in. The box store house, 275 feet distant, was badly damaged.

Logs from the barricade and cribbing were thrown as far as 275 feet, and metal from the machines was thrown an equal distance. A monkey

wrench landed on the roof of a magazine 275 feet away. In a southeasterly direction, small debris was projected 900 feet from the explosion, and glass was broken 1320 feet away.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Store house	Barricaded	Badly damaged	275
Area of structural damage			275 feet
Charted			275 feet
Missiles thrown, up to			900 feet
Glass broken, up to			1320 feet

NORTH BRANCH, MARYLAND

Chart No. 74

An explosion occurred at North Branch, Maryland, on the B. and O. Railroad, on September 23rd, 1904, at 1:05 P. M.

A wagon, loaded with 19 boxes containing 950 pounds of dynamite, started to cross the railroad track at a crossing just east of a telegraph tower. The driver did not look to see whether a train was coming. An eastbound fast freight struck the wagon; the dynamite exploded under the forward part of the engine on the left hand side, derailing the engine, the tender, and nine cars.

Two men were killed; a brakeman, caught under the wreckage, killed instantly, and the engineer injured so seriously by the explosion and by being scalded, that he died almost immediately. Two men were injured, the fireman and the operator on duty in the telegraph tower, who was badly cut by flying glass. Neither the driver of the dynamite wagon nor the horses were injured to any extent.

The telegraph tower was partly protected by the engine and the train, so that the upper part of the tower was most seriously damaged. The first house east of the tower was approximately 150 feet from the scene of the explosion. It was badly shattered, all the windows were torn out, and part of the outer wall of the building on the side next to the explosion was torn away. The second house east of the tower was another frame building, located about 225 feet away, was damaged practically in the same way. Another frame house about 150 feet from the explosion to the south was also badly shattered, although it had more protection than the other two. 300 or 400 feet away were some shanties belonging to contractors. These shanties were also badly damaged, and several other houses in North Branch had window frames broken.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Frame shanties	Not protected	Badly shattered	400
Area of structural damage.....			400 feet
Charted.....			200 feet
Missiles thrown, up to.....			no record
Glass broken, up to.....			no record

LOWER HOPE POINT, KENT, ENGLAND

Chart No. 141

An explosion occurred in a cordite mixing house of powder factory at Lower Hope Point, Kent, on December 15th, 1902, at 1:33 P. M.

The building was 18 feet long by 12 feet wide, with a porch 12 feet by 10 feet. It was constructed of wood, with a roof of corrugated iron and a concrete floor, covered with sheet lead. The interior with the exception of the floor, was lined with varnished match-boarding, and the floor was kept thoroughly wet. The building was not barricaded.

On the day of the accident, the two men employed in this building had returned to work as usual at 1 P. M. after having had their dinners. After 1:30 and just before the explosion took place, it appears that a workman employed in the cordite stoves about 350 feet away, had passed the front porch of the cordite mixing house and had exchanged a few words with one of the operators, who was then standing at the door. As he walked on, he noticed that the operator had turned away into the building, and shortly afterwards the contents of the building blew up. The time was then 1:33 P. M.

997½ pounds of nitroglycerin and guncotton cordite were in the house at the time. The process was as follows: The full boxes of unmixed paste would be stacked in the right hand corner, the mixing platform and sieve in the center of the building, and the rack on which the filled bags of mixed paste were deposited was in the left-hand corner nearest the door. The two men would lift a box of paste on to the platform, after having removed the lid and given the ingredients a rough hand-mixing. The paste would then be rubbed through the sieve into the sailcloth bag underneath. One of the men would then remove the bag and deposit it on the rack, while the other carried the empty brass-lined box out on the porch. Or, the two men would together close and take away the bag, and one of them would then carry out the empty box, while the other removed the lid from another full box and roughly mixed the contents.

As is usually the case, the building and its contents having been totally demolished, it was not possible to determine the exact operation that was in progress, much less assign a definite cause for the explosion. Spontaneous ignition due to instability of the ingredients could not well have been the cause, since the superintending chemist reported that the nitroglycerin and guncotton of the batch that exploded had given heat tests of 22 minutes and 15 minutes respectively—very satisfactory figures.

After careful consideration, there were but two explanations offering any degree of probability; ignition by a spark due to electricity generated by the friction between the hands of the workmen and the dry guncotton; and detonation of a film of explosive by concussion, or friction in connection with the handling of the brass-lined boxes.

As regards the electrical possibilities, guncotton is no doubt a dielectric, and as such can be excited by friction by the human hand. That strands of cordite passing over the hand of an insulated man can so charge him as to cause a spark to pass to earth was somewhat dramatically proved by an accident which occurred in a cordite press house. A workman, shod with rubber soles, who had for some time allowed strands of rifle cordite to run over his hand, observing a broken strand, extended his hand to the acetone pan for the purpose of rejoining the parts. A spark thereupon passed from his hand to earth, igniting the acetone vapor. After a thorough consideration of the circumstances, the electrical theory may be dismissed as an improbable explanation in this case. Even though a spark were to pass, it is difficult to see how detonation could be caused without a preliminary fire which would warn the workmen; but that they were both in close contact with the explosive was only too evident.

In regard to the theory of friction in the handling of the brass-lined boxes causing detonation of a film of explosive, this source of danger is limited to the boxes simply because with the exception of the sieving frame there was practically nothing else in the building which could give rise to friction of sufficient intensity to originate an explosion. The brass-lined boxes, full and empty, were as a rule piled up in three tiers, rendering a fall of one or two feet not impossible; secondly, it was customary to remove the lid from a fresh box before removing the empty one from the mixing platform, thereby exposing two independent brass surfaces at the same time; and thirdly, one of the deceased was seen shortly before the explosion carrying a box by himself without help from his mate, and although this box was most probably empty, the mere fact indicates that it was possibly usual to move two boxes at the same time, with consequent liability of collision between them.

It is probable that the accident may be attributed either to the fall of one brass-lined box on another, or to a collision between two of these

boxes.

The two men in the building in which the explosion occurred were killed. One man was badly hurt by flying debris.

The crater caused by the explosion was nearly circular, about 16 feet in diameter and 4 feet deep. The concrete foundations of the building 18 inches thick, were scattered in all directions in blocks measuring not more than a cubic foot, and the corrugated iron roofing sheets were torn into small pieces, which were in turn curiously twisted up into rolls; a portion of the tram rails in front of the building were lifted and thrown to a considerable distance.

The buildings in the vicinity were damaged as follows:

Building 150 feet away. Side nearest explosion blown out, other sides slightly shaken.

Cordite stoves, nearest compartment 360 feet away, door unhinged, as was the case with most of the other compartments; the farthest compartment of all, 450 feet away, had a hole driven through the roof by flying debris.

Building 225 feet away, protected by a good mound of earth, had its door facing the explosion unhinged.

Magazine 501 feet from the explosion, protected by an earth mound which was in need of repairs, had the upper bolt torn off both of the two iron doors.

The wash water house, 150 feet away, had the iron roofing sheets shifted and match boards sprung.

The final washing house was very slightly damaged.

There was considerable breakage of glass throughout the factory.

A long piece of tram rail was found lying 225 feet distant from the site of the explosion. A hole was driven through the roof of a building by flying debris at a distance of 450 feet.

The protection afforded by mounds was most noticeable, and points to the conclusion that every building which contains a substantial quantity of explosives should be separately and independently protected, irrespective of such mounds as may be erected around neighboring buildings. Although the radius of damage due to the actual explosion is as a rule fairly proportionate to the quantity of explosives involved, and the distances between the buildings regulated accordingly, yet the effective range of projected debris is always an indeterminate quantity, and the multiplication of mounds is the only available method of obtaining a reasonable degree of security against the explosion of one building being by this means communicated to another.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Frame building	None	Side blown in, sides shaken	150
Washing house	None	Iron roof sheets shifted matchboards sprung	150
Area of structural damage.....			150 feet
Charted.....			75 feet
Missiles thrown, up to.....			450 feet
Glass broken, up to.....			no record

UPLEES MARSHES, FAVERSHAM, ENGLAND

Chart No. 143

An explosion occurred in the nitroglycerin final washing house at the powder factory at Uplees Marshes, Faversham, England, on November 9th, 1903, at 2:52 P. M.

The building was surrounded with a mound of earth revetted with timbers, which completely enclosed it with the exception of an opening in front of the door. The opening was screened by an outer mound which was unrevetted.

On the morning of November 9th, work was proceeding as usual. At 9:30 A. M. a sample of nitroglycerin was taken from a batch of 1000 pounds which was in process of being washed in this building. It gave an unsatisfactory test. The process of washing was continued, and at 1:30 P. M. a second test showed that it was too alkaline. A message came that it should be double-filtered.

The operation of double-filtering consists in passing the sample through two filters containing common salt, by means of which the moisture is extracted, and with it generally the remains of carbonate of soda. The filter consists of a lead funnel standing on a tripod of brass wire in a shallow leaden tray. Though small, this filter was of considerable weight, especially when the funnel was filled with salt.

This operation was carried on by the chemist and the operator. The sample was taken to the laboratory, and at about 2:50 P.M. a boy was sent with a message that the sample was still too alkaline to test. This boy replaced the sample bottle in another building, and seeing the leading nitroglycerin hand on the plant, he went to him and told him the result. The man went to the washing house, while the boy walked in the direction of the office. Immediately after, at 2:52 P. M., the explosion occurred.

The cause of the accident was unknown. It appeared probable that the operator would turn his attention to the sample filters which had failed

to free the sample from alkali. It is possible that he might have upset or dropped one in lifting it up, either for the purpose of examination or in order to empty the tray into the wash tank. Such a fall would have been enough to cause an explosion, and the quantity of nitroglycerin present in the trays, about 3 pounds, would have been quite sufficient to explode the charge in the wash tank.

The operator was killed instantly, and six men were slightly injured by glass and falling debris.

Of the building and the apparatus which it contained practically nothing remained. The crater caused by the explosion was about 30 feet in diameter and from 4 to 5 feet deep. The revetted mound was completely swept away, its debris being scattered for about 150 feet in the form of a cross, the arms of which corresponded with the sides of the building. The unrevetted mound in front of the entrance remained comparatively intact, partly because of its greater distance from the explosion, and partly because a mound having a broad base offers greater resistance to the explosive wave, and is consequently more effective as a screen.

The structural damage to buildings in the vicinity is as follows:

Building	Feet Distant	Extent of Damage
Final washing house	129	One side shattered. Roof blown down at one end and partly supported by the tanks. Broken glass and debris all over the floor.
Glycerin storehouse	111	Wall facing explosion blown in. This building was of brick. All the others were lightly constructed of wood.
Final washing house	111	Side facing explosion badly shaken and partly thrown down. Filter fell into filter tank, which was empty.
Soda storehouse	60	Completely wrecked.
Secondary separating house	192	Side facing explosion badly shaken and partly blown in. Door at back shaken out.
Acid recovery house	192	This is another portion of the same building, much more damaged. It had not been repaired since the last explosion.
Nitrating house	120	Damage very similar to that of Final washing house.

The amount of heavy debris projected appears to have been smaller than might have been expected. No injury to persons or buildings was caused by flying fragments. The greatest distance recorded for debris was 150 feet. A great many windows were broken throughout the factory.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Separating house	Completely barricaded	Side partly blown in	192
Area of structural damage.....			192 feet
Charted.....			192 feet
Missiles thrown, up to.....			150 feet
Glass broken, up to.....			no record

ROBERTS' LANDING, CALIFORNIA

Chart No. 109

An explosion occurred on an explosives factory at Robert's Landing, California, on February 17th, 1910, at 11:15 A. M., originating in dry house No. 1 and followed by explosions in the other two dry houses.

These buildings were situated 200 feet distant from each other in a straight line. None of them were barricaded.

About 1000 pounds of dry nitro starch in boxes of 150 pounds each was stored in the first dry house*. At the time the accident occurred, two dry house men were in the act of loading one of these boxes on a truck, preparatory to going to the mixing house. The dry nitro starch in each end of the building exploded, at the same time scattering the material in process of drying at the center of the house. This explosion caused the contents of dry house No. 2 to explode, and this in turn exploded the contents of No. 3.

The cause of this explosion is unknown. One theory was that it might have been caused by overheating the drying house. Another theory was advanced that the trouble started by friction in moving one of the boxes of dry nitro starch.

In this explosion 9 men were killed, 5 were killed instantaneously, and 4 were so badly injured that they soon died. There were 14 men injured, many of them Chinese workmen.

In the combined office and laboratory building were the plant superintendent and the chemist. The chemist was instantly killed, but the superintendent managed to escape from the building. He sustained an injured arm, and burns from the fire that destroyed the house.

The explosion in the No. 1 drying house started fires in and caused the destruction of the powder mixing house, hand punching house, powder packing house, boiler house and nitrating house. There was practically complete destruction within 500 feet.

The remaining buildings were all damaged, but not a total loss.

There was practically no damage to outside property, except for broken

windows. Glass was broken in the surrounding country to a distance of two miles.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Plant building	Not barricaded	Completely destroyed	500
Area of structural damage.....			500 feet
Charted.....			250 feet
Missiles thrown, up to.....			no record
Glass broken, up to.....			2 miles

*Reports vary as to the quantity of explosives involved. There may have been 1000 pounds of powder at each end of the building, making a total of 2000 pounds.

ASHBURN, MISSOURI

Chart No. 6

There was an explosion of nitroglycerin at the high explosives factory near Ashburn, Missouri, on December 23rd, 1909, at 9:45 A. M.

The nitroglycerin was being transported from the storehouse to the gelatin mixing house on a tram car when the accident happened. There was 1080 pounds of nitroglycerin in copper cans, 30 pounds to the can, which were fitted into rubber-cushioned partitions or pockets in the tram.

The accident took place at a switch point, and was probably due to the derailling of the car with sufficient momentum to detonate the explosive.

The car was destroyed, the driver was killed, also the mule hitched to the car. Two men on a dope truck about 80 feet from the explosion, were bruised on body and legs and slightly cut on face and hands. The mule drawing the dope car was so badly shaken and bruised that it was necessary to kill the animal. Six men in neighboring buildings were slightly cut by flying glass.

The machine parts storehouse which was practically on the site of the explosion, was demolished, and its contents damaged.

The gelatin mixing house, 115 feet away, and the gelatin cartridge house, 160 feet away, were both badly damaged. The damage to other buildings on the Gelatin Line, was slight, and consisted principally of broken windows and doors.

Some glass was broken in the safety area and on the Dynamite Line, up to about 1200 feet from the site of the explosion.

Missiles were thrown to a distance of 300 to 400 feet.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Gelatin cartridge house	Timber and the lay of the land	Roofs and sides damaged	160
Area of structural damage			160 feet
Charted			160 feet
Missiles thrown, up to			400 feet
Glass broken, up to			1200 feet

LEWISBURG, ALABAMA

Chart No. 91

An explosion occurred at the Sterling Explosives Works at Lewisburg, Alabama, on August 19th, 1907, at 9:30 A. M.

The building in which the explosion happened was the Kimber machine house. A nearby hill formed a natural barricade.

Repairs had been made to several of the parts of the Kimber machine on Saturday afternoon and Sunday, and the man who made the repairs reported that he left everything in good condition. One of the supervisors who was in the building thirty minutes before the explosion reported that, so far as he was able to determine, everything was working properly.

There was about 1300 pounds of 40% dynamite in the building at the time. The cause of the accident was unknown. The four men who were working in the building were killed instantly; no one else was injured.

There were three distinct craters on the site of the building. The largest of these was located at about the door of the building, showing that most of the powder in the house had been packed, and was stacked up near the door waiting to be taken to the box packing house. The second largest crater occurred about the center of the building where the machine stood, and the third crater slightly to one side, showing that a small quantity of powder was either in the box from which they shovelled on to the machine, or else was in a mixing house box slightly to one side.

The damage to the plant aside from the Kimber machine house was slight. The mixing house, 375 feet distant, had its side towards the explosion pulled out about 12 to 15 inches, and the side of the No. 2 punching house, 265 feet distant, had its side pulled almost as much, besides pulling off the door and the shed over the door. The small change house, 140 feet distant, on the hillside above the Kimber house, was wrecked. The office lost a few bricks from the chimney and some glass. A timber about 8 feet long was projected about 500 feet.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Dynamite mixing house	Hill	Side pushed out	375
Area of structural damage			375 feet
Charted			375 feet
Missiles thrown, up to			500 feet
Glass broken, up to			no record

ASHBURN, MISSOURI

Chart No. 4

On May 3rd, 1906, at 1:35 P. M., an explosion occurred at the high explosives works located near Ashburn, Missouri.

The explosion originated in the gelatin cartridge house, and involved a guncotton drying house.

The gelatin cartridge house was of wood frame construction and equipped with one cartridge (sausage) machine, driven by a 2 H.P. motor placed in a detached room.

The guncotton drying house was built of wood frame, sheathed with boards and further sheathed with corrugated iron sheets.

At the time of the explosion, the cartridge machine was cartridging 50% gelatin dynamite in $1\frac{1}{8} \times 8''$ cartridges. About half an hour previous a machinist stopped in the house and conversed with the operator, who reported the machine as running all right. Immediately preceding the explosion, the line foreman operated the machine, while the regular man trucked a load of powder to the cartridge wrapping house. He reported that the machine was in good condition. Upon the return of the regular operator, the foreman left the building and in about two minutes the explosion occurred.

The guncotton drying house was 450 feet away from the gelatin cartridge house, and men who went to fight the fires following the flash in this house were not aware for some time of the gelatin cartridge house explosion. The field of the motor from the gelatin cartridge house, weighing probably 150 pounds, was found on the far side of the guncotton drying house, buried in the creek bank in a position which indicated that it had been projected through the house, and probably caused the explosion there.

In the gelatin cartridge house there were 1300 pounds of 40% gelatin dynamite in powder boxes.

The guncotton drying house was in operation at the time (temperature 104° Fahr.) and contained 900 pounds of nearly dry guncotton in trays;

in the ante-room, 300 pounds of dried guncotton in bags, and 450 pounds of wet guncotton. The wet guncotton was mostly recovered, so that the amount that flashed was 1200 pounds.

What caused the explosion in the gelatin cartridge house could not be determined.

As a result of the explosion in the gelatin cartridge house, the building was completely demolished. The adjacent buildings, two gelatin wrapping houses, in operation at the time of the accident, distant 160 feet on each side of the mixing house, and protected by a crib or double-faced end barricades and by the lay of the land, were damaged to the extent of broken windows. The only other damage was in the safety area of the works, where a couple of brick buildings about 450 feet from the gelatin cartridge house had gable ends started.

The guncotton drying house was blown apart, and burning pieces of the building spread over the ground up to 150 feet. The blower was not seriously damaged.

Some missiles, principally parts of the cartridge machine, were thrown as far as 1040 feet.

Very few windows were broken and this class of damage did not extend beyond 1200 feet from the explosion.

The operator and helper working in the gelatin cartridge house were both instantly killed, but no one was injured.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Brick buildings	Artificial barricade	Gable ends pulled loose	450
Area of structural damage.....			450 feet
Charted.....			450 feet
Missiles thrown, up to.....			1040 feet
Glass broken, up to.....			1200 feet

The explosion of the 1300 pounds of 50% gelatin was considered to have caused the damage cited above.

SCHAGHTICOKE, NEW YORK

Chart No. 162

An explosion occurred at the powder works, Schaghticoke, New York, on May 21st, 1912, at 7:55 P. M.

The building in which the accident occurred was the corning mill, which was barricaded. There were 1500 pounds of black sporting powder in the building, but the mill was not in operation at the time of the explosion,

which was caused by lightning. No one was injured.

The farthest distance at which actual structural damage was done in an unbarricaded direction was 500 feet. In a barricaded direction, the distance was 325 feet.

The Press House, 325 feet distant, surrounded by crib barricades and screened by the barricade of the corning mill, had two 2 x 6 studs on one side split inwards, sash and skylight were blown in, and doors were torn off. The plumbago storehouse, about the same distance away and unbarricaded, was not damaged nearly so much as the Press House.

A piece of 2-inch shaft, 3 feet long, was found 800 feet distant, the greatest distance from the explosion at which any missile was found.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Press	Barricaded	Studding split, wardens out	325
Area of structural damage.....			325 feet
Charted.....			325 feet
Missiles thrown, up to.....			800 feet
Glass broken, up to.....			no record

CHATTANOOGA, TENNESSEE

Chart No. 23

There was an explosion in a powder magazine near Chattanooga, Tennessee, at about 1 P. M. on Sunday, July 12th, 1903.

The explosion occurred in a brick building known as the Forcite magazine, and formed one of a group of magazines situated in a wooded district. It was rather isolated from the other magazines, surrounded by woods, and a hill also afforded protection in one direction.

There was 1500 pounds of dynamite in the magazine, consisting of 23 cases of Forcite 60% dynamite, 2 cases of Red Cross 60%, and 5 cases of Red Cross 40% dynamite.

Lightning struck the magazine and caused the explosion. The force of the explosion seemed to come directly from the two ends of the magazine, and the greatest force was in the direction of the Rossville Road.

Two sheet iron portable magazines, at distances of 240 and 270 feet respectively, were sprung slightly in the middle seam at the back near the roof, where the side pieces were bolted through the triangular piece forming the peak. There was also a hole 1½ inch in diameter in the back of one of the magazines, caused by a missile.

Another magazine, 425 feet away, was parted at the peak of the roof

and had one or two bricks loosened. This magazine received some slight protection from the hill.

Another magazine 425 feet away had the door facing the Forcite magazine completely torn out, including the entire door sill, with the exception of the top cross-piece. This might have been due to poor construction. The peak of the roof of this magazine was also separated, and the back half of the roof somewhat dislocated. This magazine was more protected by the hill than any of the others, and yet it suffered the most damage, which may have been due to the fact that it was in the direct path of the explosive force.

A few cases of dynamite were thrown into the middle of the floor in the nearest magazine, and in one of the others the stock was also slightly disarranged.

As to damage to dwellings in the vicinity, the Corbly house, 825 feet away across the Rossville Road, appeared to have suffered the most. It was slightly wrenched, and 30 or 40 window lights were broken.

The Arthur house, 550 feet away, had several window lights broken. The Cheek house, 650 feet away, was somewhat jarred, and the fruit trees around it were more or less damaged by missiles.

There were no injuries resulting from this explosion.

Portions of the magazine were thrown to a distance of 800 feet. Window glass was broken up to a distance of about a quarter of a mile.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Magazine	Hill and timber	Door torn out, peak of roof separated, back of house dislocated	425
Area of structural damage.....			425 feet
Charted.....			425 feet
Missiles thrown, up to.....			800 feet
Glass broken, up to.....			1320 feet

PLYMOUTH MEETING HOUSE, PENNSYLVANIA

Chart No. 77

An explosion occurred at Plymouth Meeting House, Pennsylvania, in the Keystone Quarry, on January 6, 1909, at 5:30 P. M. The explosion was in a magazine which served both for storage and as a thawing house.

The magazine was located in the quarry which was about 600 ft. long north and south, and 250 ft. wide east and west, and of an average depth of 60 feet. The country above the faces of the quarry was comparatively level.



There were 1500 lbs. of 40% dynamite in the magazine at the time of the explosion. The quarry operations had stopped for the day before the explosion occurred and there was no loss of life. The magazine was equipped with pipes and heated by live steam, and it was not an unusual occurrence for dynamite boxes to be left in contact with steam pipes, and it is probable that this was what caused the explosion. The effect of the explosion and damage done was as follows:

Engine House—Built of 1" boards, unprotected. House completely demolished and debris scattered about. Steam pipe connections were broken and pipe thrown some distance.

Blasting Supply Magazine—Size 6ft. by 8ft., built of 1" boards, about 75 ft. from magazine and unprotected. One corner was completely cut away, wood splintered, and the remainder of the building intact. This building contained electric blasting caps when the explosion occurred.

Office—Built of studding, plastered inside and out, 120 ft. from the magazine, protected by face of quarry. This was an old fashioned building, possibly 60 years old. The doors were blown in and rafters broken. This building, although only 120 ft. from the magazine, did not suffer as much as a dwelling 440 ft. distant, which indicated the benefit of the protection afforded by the quarry face.

Stone Dwelling—Substantially constructed, 440 ft. distant, protected by quarry face. A porch roof was blown in and ceiling cracked. Broken glass from the windows was blown with considerable force against the walls, furniture, etc.

Big Barn—Substantial construction, 465 ft. distant, protected by quarry face. This barn suffered considerable damage, having had the purlins, studding and weather-boarding pulled out of it.

Between 500 ft. and 2600 ft. there were five stone dwellings, a large frame dwelling, an engine and boiler house, railroad station, and a small village of about 30 houses. The principal damage occurring in this area was the breakage of glass. There were a few instances where doors were pulled loose.

A church, 2400 ft. distant, and protected by the quarry face, had several windows broken.

The only injuries caused by the explosion were a few people cut by flying glass or hurt by falling objects. A man standing inside of the barn 465 ft. distant from the explosion was knocked down and the door blown on him, but he was only slightly hurt.

The damage done by this explosion appears to have been peculiar, in that buildings close to and protected by the quarry face were only slightly damaged as compared with buildings at a greater distance from the ex-

plosion. This can probably be explained by the fact that the vacuum produced by this explosion was evidently quite severe.

The buildings shown on the attached sketch are as follows:

No. 1—Magazine in which explosion occurred.

No. 2—Engine House.

No. 3—Blasting Supply Magazine.

No. 4—Office.

No. 5—Stone Dwelling.

No. 6—Big Barn.

No. 7—Large frame dwelling.

Nos. 8 to 12 incl.—Five stone dwellings.

No. 13—Engine and Boiler House.

No. 14—Railroad Station.

No. 15 to 55 incl.—Dwellings in village.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Office dwelling and barn	Ledge	Rafters broken, purlins and studding blown out in places	600
Area of structural damage.....			600 feet
Charted.....			600 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			2 miles

LANDING, NEW JERSEY

Chart No. 47

An explosion occurred in the guncotton dry house at the explosives works, Landing, New Jersey, on August 31st, 1907, at 12:05 P. M.

This building had no barricade.

The house had been closed for the day. The workman in charge had left at 11:30 A. M. He reported that before leaving the house, he had turned off the steam from the radiator coils, and that when he left, the temperature of the dry room was between 113° and 115° Fahr. The explosion was followed by fire, but diligent search failed to disclose that it was preceded by fire.

The engine which operated the fan was left running slowly, as was the custom. There were three men nearby at the time of the explosion, one of them in the shell house and two just outside, in full view of the dry house. Those who stood in full view of the dry house would in all probability have seen a fire if there had been one preceding the explosion. They stated,

however, that the first knowledge of any trouble was the explosion itself.

In the building at the time of the explosion was 640 pounds of dry guncotton, and 1600 pounds of wet guncotton, equivalent to 1058 pounds of dry, making a total of 1698 pounds of dry involved in the explosion. It was the 640 pounds of dry guncotton which detonated. No one was killed or injured.

Comparatively little structural damage was done to surrounding property. The principal damage was in the shell house, which was considerably shattered. Some damage was done in the separating house about 600 or 700 feet away, but this damage was confined to broken window glass and sashes.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Shell house	No barrier	Considerably shattered	125
Area of structural damage.....			125 feet
Charted.....			65 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			700 feet

ASHBURN, MISSOURI

Chart No. 5

There was an explosion at the high explosives factory near Ashburn, Missouri, on September 26th, 1906, at 1:59 P. M.

The explosion occurred in the gelatin cartridge machine house. The building was of wood frame construction and equipped with one cartridge (sausage) machine, driven by a 3 h. p. electric motor placed in a detached room.

At the time of the explosion, the cartridge machine was running $\frac{7}{8}$ inch diameter 40% gelatin dynamite, and about 1700 pounds of powder in bulk and on the cutting boards was in the building. The line foreman had been helping in the house a considerable part of the day, and apparently everything was in good order when he left the building a few minutes before the explosion.

The cause of the explosion was not determined.

As a result of the explosion, the gelatin cartridge house was completely destroyed. Three men were in the house at the time of the explosion, one running the machine, one feeding powder into the hopper, and the other handling the powder as it was delivered by the machine. These men were all killed. Several employees in the No. 2 gelatin wrapping house were slightly cut by glass.

The structural damage was as follows: The No. 2 wrapping house, 110 feet distant, although protected by barricades, was badly damaged, and the end next the cartridge house nearly torn out. The gelatin dope house, distant 220 feet, was badly shattered, though protected by the configuration of the ground. The next nearest buildings, distant between 300 and 400 feet, suffered no structural damage.

Some missiles, part of the motor, were propelled about 400 feet. The breakage of windows occurred up to about 850 feet from the center of the explosion.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Gelatin dope house	Natural configuration of ground	Badly shattered	220
Area of structural damage.....			220 feet
Charted.....			220 feet
Missiles thrown, up to.....			400 feet
Glass broken, up to.....			850 feet

CHILWORTH, ENGLAND

Chart No. 124

An explosion occurred in a press house in the gunpowder factory at Chilworth, England, at about 9:30 A. M. on February 10th, 1879.

This was one of the oldest gunpowder factories in England, dating from 1590, when the Evelyns are said to have brought the art of making gunpowder from Flanders. As the site was selected at a time when the country was not densely populated, it was not chosen with respect to any advantages of sheltering mounds or hills. The country was generally flat.

The press house in which the explosion occurred was a wooden building with slated wood-lined roof, and stood on a six-foot foundation wall of brick. In this building the breaking down of mill cake and the pressing of gunpowder were carried on.

Only two men were at work in the building at the time of the explosion; both were killed instantly, and their bodies were projected nearly 390 feet from the exploded building.

The quantity of gunpowder which exploded was at least 1800 pounds, and with dust made a total of not less than 2000 pounds. About 900 pounds was in the press under confinement favorable to the development of force.

Injury inflicted on the factory buildings was inconsiderable, attributable to the facts (1) that the press house itself was so situated that two of

its sides, one of them being the side towards the west or main portion of the factory, were in a great measure backed by an excavated bank, brick-rivetted; (2) that various mounds and screens had been erected at different parts of the factory, and (3) to the presence of numerous large trees, which at places formed an almost impenetrable screen.

The cause of the explosion was unknown; the theory advanced was that it might have been caused by the presence of some foreign substance in the breaking down machine.

The damage to the factory was as follows:

Beyond the press house, where the explosion took place, there were six powder buildings in an easterly direction.

Middle glazing house, distant 285 feet, and in great measure screened by an earth mound about 10 feet thick. This was a wooden building with tiled roof, and the only injury was some broken windows and frames; in one case the whole window frame was blown out. None of the tiles were disturbed, although these were above the mound and did not benefit from its protection.

The packing house, distant about 369 feet and screened by the mound above mentioned, by a second mound to the east of the middle glazing house, and by the glazing house itself, sustained no injury.

The stove, distant 660 feet, and screened by the glazing house and the packing house and the mounds above mentioned, had glass in two of its windows broken and lead setting of one of the windows drawn out and bent.

The upper magazine, distant about 850 feet, the corning house, distant about 1060 feet, and the upper glazing house sustained no injury except a few panes of glass broken in the corning mill.

The greater number of buildings were to the west and northwest of the exploded building, and in this direction the nearest building was the incorporating mill, distant 135 feet from the press house, partially screened by mounds. This mill, constructed of boards lightly nailed to a wooden frame, with roof of the same construction, sustained considerable damage. A large proportion of the boards were off the sides towards the press house; the front, back and roof were almost completely stripped; some rafters were broken. This was the only real structural damage in the factory.

Other mills stood at distances of about 190 to 440 feet, more or less screened by numerous trees, by corrugated iron screens and by slight undulations of the ground, and to some extent by low mounds. The damage was confined to the stripping off or disturbance of a few of the lightly fastened timbers.

The engine house, a masonry building at somewhat less than 270 feet distance, and to somewhat screened, had its windows broken, some of its

window frames slightly broken, and some loose mortar shaken down.

The watch house, distant about 360 feet, had some tiles disturbed and a few stripped off. Portions of the lath and plaster ceiling had fallen.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Incorporating mill	Screened	Boards torn off sides and roof, rafters broken	135
Area of structural damage.....			135 feet
Charted.....			135 feet
Missiles thrown, up to.....			600 feet
Glass broken, up to.....			1320 feet

UPTON TOWANS, CORNWALL

Chart No. 144

An explosion occurred on an explosives factory at Upton Towans, Cornwall, England, on January 5th, 1904, at 10:55 A. M.

The building in which the explosion occurred was the precipitating house, and was communicated to the final washing house, 369 feet distant.

On the morning of the 5th of January, work was proceeding as usual, the nitroglycerin portion of the factory being engaged for the time exclusively in the manufacture and supply of this explosive for cordite paste. The nitroglycerin, after leaving the final washing house, passed into the precipitating house, where it was allowed to stand for a certain time in order to separate by gravity from any moisture which it contained. The precipitating building was fitted with three leaden tanks capable of containing about 2400 pounds of nitroglycerin, this being the quantity allowed in this building. The nitroglycerin was conveyed for the 369 feet between the final washing house and the precipitating house by means of a leaden gutter.

At about 10:55 the explosion occurred almost simultaneously in both these buildings. Two or three minutes before, two service waiters had been at the precipitating house, and had received four bags of guncotton into which nitroglycerin had been poured in the proportion required for cordite paste. They were about to bring up fresh bags of guncotton from another building to the precipitating house to receive their charges of nitroglycerin when the explosion occurred. At that time only the operator was in the building. One of the service waiters remembered that before leaving the building, the operator in the building mentioned that he would require more nitroglycerin, and heard the charge begin to run into one of the tanks from the final wash house.

Unquestionably the explosion was communicated between the two buildings by means of the gutter through which the nitroglycerin was flowing at the time. The gutter was completely demolished throughout its whole length.

The quantity of nitroglycerin present in the two buildings was about 4200 pounds, probably distributed as follows: In the final washing house 4 whole charges, or 2000 pounds; in the precipitating house about 1700 pounds; while one charge, or 500 pounds, was in course of running between the two buildings, with the greater quantity in the final washing house.

From the evidence gathered it was affirmed that the explosion originated in the precipitating house, and this narrowed the field of inquiry as to the most probable cause. Bearing in mind that at the time of the accident a charge of nitroglycerin was coming down from the final washing house, it is probable that the operator was engaged in watching this, and for that purpose was lifting the lid of the tank into which the liquid was flowing. These lids were constructed of wood covered on the under side with lead, and so shaped as to project slightly into the interior of the tank. The reason for the lead covering was to protect the wood from becoming saturated with nitroglycerin from the splash of the charge flowing into the tank. Owing to their weight and shape, these lids would give a heavy, glancing blow to the lead of the tank if allowed to fall, and they would probably always be covered with a film of nitroglycerin, especially at a time when a charge of nitroglycerin was flowing into the tank. Therefore, the most probable cause of the explosion was the accidental dropping of the lid of the tank into which the charge was running.

The three operators in the washing house and the operator in the precipitating house were killed. One man was seriously injured by the collapse of a building, and another was struck on the shoulder blade by falling debris, causing a slight fracture of the bone. Some were slightly injured by falling glass.

The two buildings were, of course, completely destroyed. On the site of the final washing house, little or no crater was formed, owing to the fact that the tanks were raised considerably above the level of the ground; but in the case of the precipitating house, where the nitroglycerin tanks were on the ground level, the explosion formed a crater in the sand 9 feet 5 inches deep. Practically nothing of the buildings or their contents remained.

The damage to the other buildings of the factory was very considerable. This was due not only to the large amount of nitroglycerin which exploded, but also to the area of effect being enlarged owing to the explosion having involved two buildings. The drowning tank, which was only about 45 feet from the final washing house, suffered most. The building enclosing this

tank was completely wrecked.

The separating house, 315 feet distant, and the wash water house, 225 feet distant, also suffered very severely. The guncotton drying house was very badly shaken and the roof partly destroyed. In this building guncotton was being dried at the time, and the risk of this being exploded by the damage to the structure must have been considerable. In addition to the above, at least 11 other buildings of the factory received more or less serious structural damage, and many more suffered from the breaking of window frames and glass.

Missiles were thrown 500 feet. A great many windows were broken outside of the factory. In this respect the town of St. Ives appears to have suffered more than Hayle, although the former was fully $3\frac{1}{2}$ miles from the factory, while the nearest houses in Hayle were at little more than 1 mile. This was probably due in part to the fact that whereas Hayle was screened by intervening sand hills, St. Ives immediately faced the factory with nothing but the sea intervening. Several plate glass windows were broken in the streets of St. Ives, and the damage also extended to the church where a large stained glass window, facing the sea, was practically destroyed. At Penzance, distant more than 8 miles from the factory, one or two windows were reported to have been broken; but this statement was unconfirmed.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Separator (between L & M)	Completely barricaded	Suffered severely	315
Area of structural damage.....			315 feet
Charted.....			315 feet
Missiles thrown, up to.....			500 feet
Glass broken, up to.....			$3\frac{1}{2}$ miles

UMBOGINTWINI, NATAL

Chart No. 111

A serious explosion occurred at the explosives factory at Umbogintwini, Natal, South Africa, on December 7th, 1909, at about 1:40 A. M.

The explosion occurred in the nitroglycerin weighing house and involved the gelatin mixing house, a mounded building 320 feet away. There was 2000 pounds of nitroglycerin and 100 pounds of nitro-cotton in the weighing house, and 800 pounds of explosive in the mixing house. It was concluded that the nitro-cotton first ignited, causing the nitroglycerin to explode, projecting heavy debris which pierced the roof of the mixing house,

and caused the second explosion, 15 or 20 seconds after the first.

The ignition in the weighing house was in all probability due to friction of the scales used in weighing out the charges. The practice was first to weigh the amounts of nitro-cotton, and then to pour on the nitroglycerin until the beam of the scales rose with the correct weight. Dry nitro-cotton dust would settle upon the beam of the balance, the platform and all bumping parts of which were insufficiently protected. The friction between the sliding weight and the beam would be sufficient to cause the ignition, which then communicated to the nitro-cotton in the boxes.

The plant was running at night. Three Europeans and 8 natives were killed by the explosion.

On the place where the weighing house had stood a crater was made 3 feet deep and 18 feet in diameter. Two holes, 5 feet deep and 9 feet in diameter, marked the place where the mixing house had stood.

A great amount of structural damage was done by the explosion. All buildings within a radius of 1000 feet were expanded in a direction toward the center of the explosion, and the roofs fell in.

A piece of lead weighing 20 pounds from the weighing house was projected 500 feet, actually piercing the roof of a house, and a concrete block weighing 120 pounds was found at a distance of 500 feet between two magazines.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Plant buildings	No barrier	Roofs sucked down and walls bulged	1000
Area of structural damage.....			1000 feet
Charted.....			500 feet
Missiles thrown, up to.....			500 feet
Glass broken, up to.....			No record

CLIFFE, ENGLAND

Chart No. 145

An explosion occurred on an explosives factory at Cliffe, Kent County, England, on February 18th, 1904, at 8:56 A. M.

The explosion happened in the nitroglycerin separating house. This building was of unusual and inconvenient construction, being round and of great height. It was surrounded by a barricade composed partly of brick-work.

On the morning of the accident, which occurred at four minutes to nine, two charges had been nitrated. Of these, one was in the pre-wash

tank situated in the same building as the nitrator and separator, and the other was still undergoing the process of separation, having only come down from the nitrator a few minutes earlier. The nitrator itself contained no explosive, as only two charges of 500 pounds of glycerin, each equal to about 1050 pounds of nitroglycerin, were allowed in the building at the same time. Two charges, or 2100 pounds of nitroglycerin, detonated.

The foreman was in the building five or ten minutes before the explosion occurred. He stated that when he left, one of the operators who had come over from one of the filter houses to say that he was ready to receive the charge from the pre-wash tank, was engaged in adding soda solution to this tank before running the charge into the final washing tank; and the other operator was attending to the separator into which the charge had been run two minutes before, and in which not more than $\frac{1}{4}$ inch of nitroglycerin had separated from the acids. As the charge then present in the pre-wash tank had not left this vessel at the time of the accident, it may be assumed that during the few minutes after the foreman had left the building, the solution had remained practically unchanged.

It is probable that the accident was caused by the spontaneous decomposition of the charge of nitroglycerin in process of separation, owing to the presence of an impurity not discovered in the sample test; and that the fatal results were due to the men in charge failing, through negligence or lack of judgment, to make use of the drowning tank until the heat from the decomposition caused an explosion which was communicated to the charge in the neighboring tank.

The two men in the building were killed instantly, and a third man was killed on the spot, although he was not actually in the building at the time, his duty being in connection with the glycerin bogie. Two men were at the windlass, protected by the mound around the building. One escaped with slight bruises; he was in charge of the nitrating plant, and had just left the building to fetch a supply of soda. The other was caught by the fall of the heavy staging forming part of the building, and was badly crushed. He died on his way to the hospital, making the fourth man killed in this explosion.

The remaining casualties were due to projected debris of the building, and more particularly of the mound, which was rivetted on the inside of the brickwork. The heavy coping had been exposed by the settlement of the surrounding earth by which it was supposed to be enclosed. The man who was most seriously hurt received his injuries in somewhat peculiar circumstances. When he saw the flash, he instinctively ducked his head. At the same moment the door of the building was blown in, striking him on the top of the head. It was thought at first that his skull was fractured, but he recovered.

The separating house in which the accident occurred was completely demolished. The scheme of construction of this building proved to be bad. The great height was inconvenient, the "round" shape cramped the interior space, and the projecting mound, although in one respect it did its duty, in another respect proved an additional source of danger, as its construction was a missile hazard.

The structural damage was as follows:

Two final washing and filter houses, each 150 feet distant from the explosion, were slightly damaged; glass was broken, and a few planks of the roof were sprung.

The hand mixing house, 291 feet distant, had its roof dented slightly in one place, and a platform on the far side broken by flying bricks.

The wash water settling house, 150 feet distant, was the most seriously damaged in the factory. The roof was practically wrecked and the house was filled with small debris.

The Nach Schneider, 150 feet distant, had three of its glass tops broken, but none of these contained nitroglycerin. There was a little explosive in three of the unbroken glasses. The front of the building was much knocked about.

The gelatin range, 390 feet distant, was not damaged, although one of the men injured was struck by flying debris while standing at the corner of this building.

Heavy masses of brickwork were thrown all over the factory, single bricks being found at a distance of 390 feet from the building. It was nothing short of miraculous that in no instance was a house containing nitroglycerin struck by debris heavy enough to penetrate. In the immediate neighborhood of the two filter houses, 150 feet distant, each containing over 1000 pounds of the finished explosive, large blocks of coping were found buried their own depth in the ground.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Wash water house	Barricaded	Roof wrecked	150
Area of structural damage			150 feet
Charted			150 feet
Missiles thrown, up to			390 feet
Glass broken, up to			No record

HAZELTON, PENNSYLVANIA

Chart No. 75

There was an explosion near Hazelton, Pa., on the Pittston Boulevard, on April 8th, 1905, at 9:03 P. M.

The accident occurred in a stone thawing magazine, about 12 feet square, with walls 12 inches thick, a shed roof, double thick wooden door, with a sash light in it, protected by a perforated steel plate. The door was on the south side. In the east and west ends were shelves on which the powder was placed.

The surrounding country was very mountainous, and covered with second growth timber. The ground was rocky, but at the point where the magazine was located there was 5 feet of earth.

All powder was left in cases on the night of the explosion. Directly opposite the door on the north side of the magazine, about 2 feet from the rear wall, was an egg-shaped stove in which was kept a soft coal fire for thawing the dynamite for use. There were some caps or detonators in the magazine, placed as far as possible from the dynamite in the southwest corner on a shelf 6 feet high. The 40% dynamite was in the west side, and the 50% and 60% dynamite on the east side. The Judson was nearest the southeast corner, almost under the caps and exploders. There must have been about 4½ feet of space between this powder and the blasting caps.

The quantity of explosives involved was:

550 pounds of rocket powder and a very little Judson—4 bags.

150 pounds of 40% ⅞ inch Forcite Red Cross.

50 pounds of 40% ⅞ inch Forcite Red Cross.

350 pounds of Emporium Mfg. Co's. "C" 40%.

500 pounds of Emporium Mfg. Co's. "D" 50%.

500 pounds of Emporium Mfg. Co's. "E" 60%.

50 14-foot SS. Victor E. B. caps.

150 Gold Medal Caps.

This gives a total of 2100 pounds of dynamite.

The chargeman stated that when he left the building at 5.45 P. M. on the night of the explosion, the fire was dying and almost out.

The cause of the accident was unknown. One theory was that the draft was left on the stove, and it became overheated and set fire to the woodwork.

No one was injured in the explosion.

There was nothing left of the magazine to show that a building had ever been there. The crater tapered to a point in the center, and was about 4 feet deep.

A stock house, 25 feet distant from the magazine to the east, was a frame building constructed of one-inch boards on a stone foundation, 11

by 18 feet, shed roof, plank floor. This house also disappeared, debris being strewn over the hillside for some distance, including pieces of machinery, boards and extra castings which were stored in the building. A small Ajax hoisting engine weighing about one ton, resting on a couple of small joists on the floor of the building, was moved 12 feet, so that it came outside of the foundation limits. The bed plate was broken and cylinder cracked, and the engine was in such condition that the Superintendent had it broken into small pieces for scrap.

A small blacksmith shop, 125 feet to the west of the magazine, 12 by 24 feet, had the east 12 foot side which contained the door facing the explosion badly damaged. The two 24-foot sides fell outwards, and the roof fell in. It was a primitive frame building, and badly wrecked.

The crushing and screen plant, 250 feet east of the explosion, was injured by a rock dropping through the roof of one of the conveyor line shafts and breaking the conveyor line. A few steam pipe joints were loosened.

The engine and boiler house was practically not damaged, except for some broken windows. This was a stone building, with a stone partition between the engine and boiler rooms. The ends nearest and farthest from the explosion were moved out from $\frac{1}{2}$ inch to an inch at the roof.

Two dwellings, 300 or 400 feet distant on the Boulevard facing the explosion, were on a lower level, about 60 or 75 feet below the magazine. The nearer building was the more shaken of the two. It was a two story frame house in front, with a peak roof, and one story in the rear. The front door was broken off its hinges, the front of the building was very badly bulged, the extreme point being the floor of the second story. Everything in both houses was pretty well shaken, articles were knocked off shelves. In two cases, burning lamps were knocked down, and fires only avoided by the quick action of the tenants. Nearly every pane of glass in both houses was broken, the glass in nearly every instance falling inside the house.

The office building, 400 or 500 feet distant and located down the hillside from the magazine, had two rooms on the first floor. On the side of the explosion a stone had gone through a window. Small pieces of glass were stuck in the far side of the room. The window sash was wrecked. The door between the rooms was knocked off its hinges. An outside door exposed to the shower of stones was knocked off its hinges by a stone.

A frame hotel 1000 feet east of the explosion faced the road in the same way that the magazine did. At about this point the shower of stones seems to have been the heaviest. One oblong stone 3 x 5 feet and $2\frac{1}{2}$ inches thick stuck in the siding under the peak of the roof. The side of the hotel towards the explosion was bulged out three inches at the bottom of the first floor. Several small frame buildings in the rear of the hotel were damaged more or less by the shower of rock.

A rock weighing 112 pounds was thrown 1000 feet and hit the side of an old barn, knocking off a few boards. Several other stones weighing about 40 pounds were thrown between 1300 and 1400 feet from the explosion. A small piece of drill that had been in the magazine was found at a point about 2000 feet from the explosion.

A feature of this explosion was that the debris and machinery were carried in a straight line from the magazine, spreading only slightly as the distance from the explosion increased. Another interesting fact was that the stones were thrown either east or west. Nothing could have been thrown north, as the wall of the magazine was against the side of the hill. A large barn 300 feet west of the explosion, a little behind the line of the shower of stones, did not appear to have suffered in any way.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Residence	No barrier	Front badly bulged	400
Area of structural damage.....			400 feet
Charted.....			200 feet
Missiles thrown, up to.....			2000 feet
Glass broken, up to.....			No record

BEAVER MEADOW, PENNA.

Chart No. 12

On the afternoon of June 24th, 1908, an explosion occurred in the powder magazine of the Beaver Meadow Stripping, located a short distance (half a mile) northeast of Coleraine, Pa., and less than a quarter of a mile east of Leviston, Pa.

The magazine was a wooden structure about 12x12 feet. The forces of the explosion appear to have gone in several directions; those in a northwesterly and southwesterly direction being the most violent. There was no artificial barricade, but a dump 60 feet to 75 feet in height consisting of refuse taken from the stripping, offered protection to the south and southwest. The explosion was caused by lightning striking the magazine during a terrific storm.

The magazine contained at the time of the explosion approximately 1000 pounds of 33% dynamite, and 50 kegs, or 1250 pounds, of black blasting powder, besides a small quantity of blasting caps, all of which exploded. There was no trace of the magazine after the explosion.

About 60 feet northeast of the magazine stood the blacksmith's shop—

a wooden building 10 x 16 feet. The building collapsed, the floor remaining intact, and everything in the shop at the time of the explosion was found under the wreckage.

About 75 feet northwest of the magazine was the engine and boiler house, and tanks, all constructed of wood. The explosion left very little of the roof and sides of this building, and the tanks had one or two boards blown off.

The nearest dwelling house, a frame building, was located about 300 feet southwest of the magazine, and 60 feet below it. The concussion caved in a portion of the roof of this house, and the sheds at the back were damaged considerably. Some of the furniture was also damaged.

Besides the damage to buildings already described, considerable havoc was occasioned within a radius of one-half mile southwest and northeast of the magazine. Doors were blown off their hinges, window panes and furniture were broken. The wind at the time of the explosion was north-westerly, with an approximate velocity of 60 miles an hour.

In the blacksmith shop at the time of the explosion were the blacksmith, another man and a boy, the two latter having gone into the building to get out of the rain. The blacksmith was killed instantly, but with the exception of a few bruises and scratches, the other two in this building were uninjured. All three were found under the wreckage of the building.

In the engine and boiler house were two men; one standing at the boiler was thrown by the force of the explosion 12 feet onto the platform beside the drum of the engine, breaking his collarbone. The other man, standing on the platform beside the drum, ready to hoist a car up the plane, was unhurt.

None of the occupants of the dwelling house were hurt, although they were knocked from their feet.

Window glass was broken up to one-half mile southwest and northeast of the magazine.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Dwelling house	Natural	Portion of roof caved in; sheds damaged	300
Area of structural damage			300 feet
Charted			300 feet
Missiles thrown, up to			No record
Glass broken, up to			½ mile

ARDEER, SCOTLAND

Chart No. 134

An explosion occurred at the explosives factory at Ardeer, Ayrshire, Scotland, on February 24th, 1897, at 6:36 A. M.

The final nitroglycerin washing house, in which the explosion happened, was of light construction, and provided with a sand floor. It was lighted partly by gas and partly by electricity, the lamps being outside the windows. The house contained two lead-lined circular washing tanks, connected with the two separating tanks by means of two leaden gutters terminating in a short leaden pipe, with an india rubber tube and brass nozzle.

The finished nitroglycerin was run into a filter tank, from which it was decanted by means of a chemicalware cock into the other ingredients of the particular explosive in course of manufacture; these ingredients being placed in the proper proportions in a brass-lined box on a scale below the cock, so that the proper amount of nitroglycerin might be supplied.

A short preliminary mixing of the ingredients took place, the box being removed to a stool for that purpose, in order that the nitroglycerin might be so far absorbed as to avoid danger in transporting the explosive to the mixing house proper, to which the boxes were conveyed on a "bogie," six at a time, covered with a tarpaulin.

At the time when the accident occurred, blasting gelatin was being made, and 150 pounds of nitroglycerin was drawn off in each box, which contained 15 pounds of nitro-cotton. The preliminary mixing occupied about one minute. Two boxes of blasting gelatin were in the course of manufacture at the time of the explosion, at 6:36 A. M.

The six men in or about the building were blown to pieces, and scattered in all directions. In addition, three men and five women were injured, none of them seriously, in various parts of the works by the fall of debris, broken glass, etc.

Serious structural damage did not extend beyond about 600 feet, and slight structural damage, (such as the fall of ceilings, etc.) ceased at about 990 feet. Glass was broken up to 1600 feet.

There were two explosions, one of a comparatively small quantity (300 or 450 pounds) of semi-mixed blasting gelatin in or at the bogie outside the building; and the other the nitroglycerin (about 1800 pounds) in and divided between a washing tank and a filter tank. The two explosions were so nearly simultaneous that only one report, followed by a rumbling noise, was heard.

The structural damage was as follows:

Building	Feet Distant	Extent of Damage
Nitroglycerin separating house	150	Shell of house shattered. Roof collapsed. Plant inside practically uninjured.
Nitroglycerin potwash house	150	Shell of house shattered. Roof collapsed.
Nitroglycerin precipitating house	69	Shell of house and roof collapsed. Plant inside uninjured.
Nitrating house	144	Porch and gable driven in. Roof covering loose and off in places. Windows and doors gone in and out. Inside plant and apparatus uninjured.
Nitrating house	144	About the same as above.
Miscellaneous store	105	Shell of house all adrift. Tanks all right.
Nitroglycerin precipitating house	105	Wooden shelter for taps gone.
Nitroglycerin wash and filter house	222	Roof collapsed by fall of piece of gutter. One side of house blown in. Front gable fallen in. Damage to apparatus.
Nitroglycerin nitrating house	246	Side end and roof practically destroyed.
Acid tank and egg	144	Shell roofing gone. Tanks, etc., good.
Wash water tank	135	House demolished. Tank good.
Cartridge making house	375	Back shaken, 3 panes glass broken out of 48.
Cartridge making houses (15)	513 to 966	Side shelters slightly shaken. Shelves knocked off.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Cartridge houses	Barricaded	Slightly shaken (see above list)	513 to 966
Area of structural damage.....			600 feet
Charted.....			600 feet
Glass broken, up to.....			1600 feet

GIBBSTOWN, NEW JERSEY

Chart No. 168

An explosion which totally destroyed the "C" gelatin mixing house at the Repauno Works, Gibbstown, N. J., occurred on September 22nd, 1913 at 9:52 A. M.

The mixing house contained at the time 1100 pounds of 60% gelatin and 1200 pounds of 40% gelatin, making a total of 2300 pounds of explosive.

The cause of the explosion was unknown. Two men who had left the

building only a few moments before, reported that everything seemed as usual. Study on the ground afterwards showed a comparatively large crater under the spot where the nitroglycerin buggy stood, which would indicate that the nitroglycerin had not yet been run into both bowls. Furthermore, the condition of the paddles showed that they were probably in a raised position, since if they had been in the bowl they would have suffered greater distortion. This disposed of the theory at first advanced that the explosion was caused in connection with the operation of lowering the paddles. It was suggested that decomposition might have started from the bowl being too hot, but this was a matter of speculation.

The crib barricades held very well, but three feet was blown off their tops.

The structural damage was as follows: The gelatin dope house, 65 feet away, was shattered; the gelatin cartridge house, at 225 feet, had doors and windows broken; the gelatin mixing house, 320 feet from the explosion, had windows and doors broken and the shed torn loose. Beyond this distance, damage was confined to broken glass and sash. A piece of the mixing bowl fell through the roof of the Kimber machine house, making a hole about 4 feet square in the roof, and another hole in the floor. As this building was not in operation, no one was hurt.

The four employees in the mixing house were instantly killed. Two other employees were slightly injured, bruised and shocked, and a third man, a trucker, about 30 feet away from the explosion, had his ear drum punctured and his eyes affected.

Missiles were thrown 500 feet, and glass was broken at a distance of half a mile.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Gelatin Mixing house	Crib barricade	Shed torn loose, doors and windows broken	320
Area of structural damage			320 feet
Charted			320 feet
Missiles thrown, up to			500 feet
Glass broken, up to			$\frac{1}{2}$ mile

BOULDER, COLORADO

Chart No. 15

At about 12:30 A. M. on August 10th, 1907, fire was discovered in some freight cars on the railroad tracks along Water Street, between 9th and 10th Streets, Boulder, Colorado. The fire burned about 30 minutes before it

reached some explosives in one of the freight cars and caused an explosion.

Shipments of powder had been delivered to the railroad on August 8th and 9th, and were loaded in four cars, as follows:

2300 pounds of dynamite and gelatin, 40% strength.

100 pounds of dynamite.

500 blasting caps.

4800 pounds of dynamite.

There was only one explosion noted, the 2300 pounds of dynamite and gelatin, and it was assumed that the 100 pounds of dynamite in the second car burned without detonating. The car containing the 4800 pounds of dynamite was moved to a point of safety at the beginning of the fire.

The dynamite and gelatin that exploded were loaded in the center of the car, and the force of the explosion was expended in a westerly direction toward 9th Street. In this direction three men were fatally hurt, and died from injuries received from projected iron and timber. The firemen who at the time of the explosion were fighting the fire from east to north, were merely knocked down.

Although the hour was late, a considerable crowd had gathered to watch the fire, and it was surprising that there were only three fatalities. There were a number of minor injuries received, but none of the bystanders were seriously hurt.

Within 50 feet of the point of the explosion, were the main freight house and some freight sheds. The damage from the explosion could not be determined, as the structures were burned up by the fire.

On the east side of 9th Street, about 75 or 80 feet away from the point of explosion, was a warehouse of wood construction, which contained some 400 pounds of dynamite and 3 kegs of black blasting powder. The end and the roof of this building were blown in, and the building set on fire in several places. The powder, however, was successfully removed and no explosion resulted.

Directly north of the track were several sheds and outhouses, distant 100 to 125 feet, which were demolished and afterwards consumed by fire. To the northeast, on 10th Street, about 125 feet away, was a two-story brick warehouse, belonging to a wholesale grocery company. This building had the edges and the roof displaced, and the walls slightly separated on the first floor. On the second floor, near the roof, there was a separation of the three layers of brick about 12 inches.

Terraces on 9th Street, 125 to 200 feet away, were damaged only to the extent of broken and fallen plaster, and of course broken glass. A house fronting on Walnut Street had plaster blown down and door frames shaken loose.

The above represents all the damage to buildings in the vicinity, with the exception of broken glass, which was considerable. This class of damage extended for several blocks and was peculiar in that a plate glass window could be blown in, while windows on each side would not be touched.

Glass was broken as far away as 1500 feet, with isolated instances up to 2000 feet.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Warehouse	No barrier	Brickwork damaged	150 to 200
Area of structural damage			200 feet
Charted			100 feet
Missiles thrown, up to			750 feet
Glass broken, up to			2000 feet

SHENK'S FERRY, PENNSYLVANIA

Chart No. 69

An explosion occurred in the McAbee Explosives Works at Shenk's Ferry, Pa., on June 9, 1906, at 12:43 P. M. There were two explosions—the first and principal one in the dynamite packing house, and the second a small explosion in the nitroglycerin house. The dynamite packing house was a frame building about 15 x 35 feet. In one end there was a kettle in which paraffin was melted for dipping shells. In the center of the building the operation of punching the dynamite into the shells was conducted, and in the other end the dynamite cartridges were boxed. It was estimated that there were about 2500 lbs. of dynamite in this building at the time of the explosion.

In the nitroglycerin house operations had just been started to make a charge of 500 lbs. of nitroglycerin, but at the time there was only about 45 lbs. of nitroglycerin in the nitrator. The explosion of this quantity resulted in a spill of the acid and glycerin in the building.

The packing house was the geographical center of the plant. There were no artificial barricades nor mounds around any of the buildings but trees formed some natural protection.

The factory was situated in a small ravine which was bounded by a hill on the northwest about 150 ft. high, rising so abruptly that it was difficult for a man to climb it without the aid of the underbrush. A hill on the south-east side of the ravine was over 200 ft. high but not so steep as the opposite hill. There was a level space about 120 ft. wide at the lower end of the ravine, alongside of which ran a broad gauge siding from the Pennsylvania Railroad. Along this trackage was the power house, box storehouse, and main

storehouse. Directly opposite the main storehouse and 120 ft. to the southeast was a packing house; 80 ft. southeast of the packing house was a mixing house and 150 ft. southeast of the mixing house was a nitroglycerin house which was on an elevation 25 ft. higher than the mixing house. The magazine, which was a light frame building covered with tar paper, was about 160 ft. east of the packing house. This magazine was filled to the roof and door with dynamite, in all about 2000 cases.

The men employed in the packing house were of an age ranging from 17 to 23 years and nearly all of them were from families living in the neighborhood. They were paid on a piecework basis and it was reported that at times they were able to get through their work and get home by 1 o'clock in the afternoon. In order to quit early, it is probable that they worked with extreme rapidity, perhaps neglecting precautions for the sake of speed. The cause of the explosion, however, is not known.

There were 11 men killed; 7 were dynamite punchers, 2 were packers, 1 the paper cutter, and the assistant foreman. Five men were injured.

The packing house was completely demolished, leaving two distinct craters in the ground. The trees for a distance of 150 ft. were blown either out of the ground or cut off short, and all shrubbery and underbrush obliterated. The structural damage was as follows:

The mixing house, 80 ft. distant, had only a few of the studding and about one-fourth of the siding left in place. The roof was crushed in and badly wrecked. In this building there were two tanks which at the time of the explosion contained about 7000 lbs. of nitroglycerin. Although the mixing house was almost completely destroyed, yet the nitroglycerin did not explode. The storehouse, 120 ft. distant, which contained sawdust, wood-pulp, sulphur, paper, etc., was demolished and set on fire. The power house, 140 ft. distant, was completely wrecked, the boilers thrown out of place and the woodwork destroyed by fire.

On the broad gauge track, directly across the level area of the ravine from the packing house, was a box car loaded with 400 cases of dynamite. This car had the roof blown off, the side opposite the packing house entirely shattered, and the upper half of the side away from the packing house badly broken. Several of the cases of dynamite were also broken open and fragments of flying debris were thrown into some of the boxes. That this car did not explode speaks well for the safety of dynamite when packed in cases ready for transportation. This car was later moved up the track by employees to get it out of the way of the burning storehouse. A tank car, also on the broad gauge siding, had the tank blown off and wooden portion of the car destroyed by fire. The office building, 600 ft. distant, had some of the clap boarding torn off and all of the windows broken. The maximum force

of the explosion was southeast and northwest, or across the ravine, while comparatively little damage was done either up or down the ravine.

On the side of the hill northwest of the ravine, about 400 ft. in a direct line from the packing house, but protected by the brow of the hill and thick woods, was a shanty which only had one window light blown out, but was so badly jarred by the effect of the explosion that considerable china and glassware was broken.

At the top of the hill, southeast of the ravine and about half a mile from the factory, was a farm house which had several window lights blown out, one door sprung, but no other damage. This house was protected by trees and the brow of the hill. A straight line drawn from the packing house to this farm house would have been about 30 ft. below the ground at the top of the hill.

The box storehouse, about 220 ft. distant, was only slightly damaged.

The original plant was cheaply constructed, all the buildings being within a radius of 300 ft., except the shell house which was 500 to 600 ft. from the packing house.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Office	No barricade	Boarding pulled loose	600
Area of structural damage			600 feet
Charted			600 feet
Missiles thrown, up to			600 feet
Glass broken, up to			2640 feet

WINSTED, CONNECTICUT

Chart No. 105

An explosion of 2500 lbs. of black powder occurred at Winsted, Connecticut, on September 20th, 1892, at 12:15 A. M., on a freight train of the Central New England Railway.

The general theory in regard to the accident was that the train broke in two while running east, just after having left Winsted, and that the first section slowed up to allow the rear section to catch it on the slight grade, where the accident occurred, and the jar of the collision caused the powder in the car to explode.

There were 18 cars in the train, which was a special freight, and no less than 7 of them were wrecked, while all were more or less damaged and shattered. The cars were scattered over the ground some distance from the scene of the explosion, and there was a crater 30 feet long and 15 feet deep under the car in which the powder was loaded. In the locomotive that hauled the

train, the cab windows were shattered, the bumper blown off, and the head-light blown to pieces.

No one was killed in this explosion, and injuries were few.

A barn situated on a hill 500 feet distant was badly damaged, and the front of a house nearby was shattered, and doors blown in.

Car wheels, track rails, coal, etc., were scattered in every direction. One car wheel was blown no less than 800 feet through the air, and landed on a neighboring hill. Another wheel, with axle attached, was hurled almost as far. A piece of iron weighing sixteen pounds was thrown about a quarter of a mile, and was found embedded in the ground in a piece of woods. A large rock blown from the ground under the powder car landed 50 feet away.

Hardly a whole piece of glass remained in a house on a hill about 500 feet away.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
House	No barrier	Front shattered	500
Area of structural damage.....			500 feet
Charted.....			250 feet
Missiles thrown, up to.....			1320 feet
Glass broken, up to.....			No record

KRUMMEL, GERMANY

Chart No. 64

An explosion occurred at the dynamite factory at Krummel, Germany, on August 3rd, 1894, originating in the nitroglycerin nitrating house, and involving the nitroglycerin final washing house.

There was present in the final washing house about 2200 pounds of nitroglycerin, and in the nitrating house 440 pounds, besides 880 pounds in the nitrating apparatus which did not explode.

At the time of the explosion the third charge of nitroglycerin, 880 pounds, was in process of being run down from the separator into the final washing house, and the fourth charge was in the nitrating apparatus, nearly ready for separation. About half of the third charge had reached the final washing house, when bubbles of gas were observed at the corner of the separator, giving off red fumes. The two men in the building, after having admitted air into the separator, and having set in motion the automatic mechanism for opening the escape cocks, rushed from the building and had reached a distance of about fifty paces when the explosion occurred. The nitroglycerin which was running down into the washing house served to communicate the explosion to the latter; and in this building one workman lost his life.

Undoubtedly the explosion was due to spontaneous decomposition, but the cause of such decomposition was not ascertained. The two previous charges were made of exactly the same material, and under the same conditions, and nothing abnormal was noticed with them.

The destruction caused was considerable; up to a radius of 231 feet, brickwork and roofs of buildings suffered considerably, while up to 657 feet, doors and windows were torn from their frames, and roofs uplifted. Traces of great air pressure were found up to 3282 feet.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Factory buildings	Barricaded	Windows and doors torn from frames; roofs uplifted	657
Area of structural damage.....			657 feet
Charted.....			657 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			No record

NANAIMO, BRITISH COLUMBIA

Chart No. 160

An explosion occurred on an explosives factory at Nanaimo, B. C., on December 22nd, 1911, at 10:30 A. M.

The explosion took place in the gelignite mixing house. This building was embanked on the two sides up to the gables. At the back there was a lower embankment near the building, and in front, at a distance of 100 feet, another embankment was interposed and protected the safety area.

In the interior of the mixing house there were two brass mixing pans of the Ardeer type, arranged along the side of the building. At the back of this there was a clear space used for storing fibre tubs, containing an ungelatinized mixture of nitroglycerin and nitro-cotton. A small room opened off this back portion. At the time of the explosion the building contained some cartons of Samsonite, which had been returned from the mines, and which were being thawed. The motor and hot water circulating arrangements were situated in a small addition at the side of the main building.

At the time of the accident, the following explosives were most probably in the building:

In tubs (mixed) gelignite.....	328 pounds
In tubs (ready for mixing).....	1015 pounds
Samsonite (thawing in annex).....	1450 pounds
Total.....	2793 pounds

Two minutes before the explosion, a Chinaman left some chalk at the building, and reported that at that time the operator was standing in between the two machines, the further one of which was empty and not in motion, while the pan of another one was being lowered by the boy. It was the practice partially to empty the pan while the blades were revolving, and then lower it away and complete the emptying process when the pan had been pulled from beneath the blades.

Witnesses agreed that there were two distinct explosions, a small one resembling a blast followed by a huge sheet of flame, and a tremendous detonation. The supposition is that the operator and the boy were carrying a tub containing 165 pounds of gelatinized gelignite out to the bogie, and that this tub had been laid down or had fallen down upon the sparred wooden grating at the front of the house. There may have been frozen gelignite either on this wood or on the bottom of the tub. The day was not a cold one, but it is quite possible that some particles of gelignite may have been left on this grating by a preceding tub and it may have been frozen. It is unlikely that there was solid nitroglycerin in the tub itself, as the latter had been in the warm house all night.

From the position of the remains of the workers, it appeared as if they were at the front of the building when the accident occurred. There were three men killed. Besides the operator and the boy helper on the spot, a man in a small building 75 feet distant was killed. One boy in the gelignite blending house, 380 feet distant, had his shoulder dislocated and was cut about the head. A man in the dynamite mixing house, 400 feet distant, was thrown against the wheel mixer and was badly bruised. Between fifteen and twenty people were cut by flying glass.

The building in which the accident occurred was completely wiped out, a deep crater alone marking the site.

Following is a list of buildings damaged:

Building	Feet Distant	Extent of Damage
Wood pulp screening house	70	Smashed to fragments.
Guncotton house	100	Total wreck.
Pack house	200	Badly smashed.
Gelatin girls' mess room	250	Badly smashed.
Gelatin rolling house	290	Badly smashed.
Monobel pack house	400	Roof sprung.
Hall machine house	450	Roof sprung.
Foreman's office	210	Badly shaken.
Dynamite mixing house	400	Roof split open.
Gelatin blending house	300	
Pack house	500	Roof split open, doors and glass broken.
Monobel dip	400	Wall forced out.

Building	Feet Distant	Extent of Damage
Ammonia grinding house	500	Roof split open, doors and windows broken.
Pulverize store	520	Roof split, doors and windows.
Box store	650	Wall forced out.
Shell house	720	Roof split open, galvanized iron torn loose, windows broken.

Brass portions of the mixing machine were picked up at a distance of 1000 feet from the explosion, and one of the foundation stones weighing about 150 pounds was found near the nitrator, 825 feet distant. A flywheel passed through the roof of the gelignite wash house, 550 feet distant.

With scarcely an exception, every building in the works had one window at least smashed, and in many instances the frames were blown in.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Shell house	Barricaded	Roof split open, galvanized iron	720
Area of structural damage.....			720 feet
Charted.....			720 feet
Missiles thrown, up to.....			1000 feet
Glass broken, up to.....			$\frac{1}{4}$ mile

MARTIN, PENNSYLVANIA

Chart No. 178

On May 13th, 1913, at 12:45 noon, an explosion occurred in two portable magazines belonging to a coal company at Martin, Pa.

These magazines were fireproof, of steel construction, about 6 x 9 feet. They stood about 10 feet apart, on rolling ground, without either natural or artificial barriers to screen them from the railroad which ran through the valley.

There were in the magazines at the time of the explosion 1000 pounds of Minute A dynamite, and 2000 pounds of Collier 5 Special, making a total of 3000 pounds of explosives and some caps and fuse.

The cause of the explosion was unknown. A railroad employee had been sent on an errand to one of the magazines which was also used as a tool house. This man was killed, at about 50 feet from the magazine. Several people were injured, though not seriously, at distances from 75 to 125 feet. There were narrow escapes from flying stones and pieces of iron.

At the time of the explosion, a local train consisting of 8 box cars, caboose and engine, was standing on the track. The box car had in it 160 cases of Monobel $1\frac{1}{4}$ x 8, and 300 pounds of Red Cross 40%, $1\frac{1}{4}$ x 8, all in 25 pound cases, also 42 cases of Cameron 1-A, which was stored in the

back end of the car, and 12 cases of fuse. This car was almost demolished, sides, door, and top being so badly broken that its further use was out of the question. Boxes of Monobel were lifted from their braced position. Several lids of the Monobel boxes and of the cases of fuse were lifted off. The explosives which were in the train had no protection except the sides of the car, yet they did not explode. The train crew had just finished unloading the freight, and would inevitably have been killed had the Monobel exploded.

Missiles were thrown 500 feet, and a jack weighing 75 pounds was carried 300 feet and driven through a building. Dwelling houses, frame and brick buildings were badly damaged, but it is estimated that serious structural damage ceased beyond a radius of 200 feet. Glass was broken to a distance of two miles.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwelling houses	No barrier	Seriously damaged	200
Area of structural damage.....			500 feet*
Charted.....			250 feet
Missiles thrown, up to.....			500 feet
Glass broken, up to.....			2 miles

*Complete later reports showed structural damage at 200 feet only.

BLACKBECK, ENGLAND

Chart No. 151

An explosion occurred in the drying stove of the gunpowder factory, Blackbeck, England, on January 19th, 1898, at 5:55 P. M.

The factory was situated on rolling ground, wooded, and the mounds and trees made natural barricades, supplemented by some artificial mounds.

The building in which the explosion occurred was a single storied stone building 33 x 16 feet, with walls two feet thick and a slated roof. It had a sheet iron ceiling, and the walls were matchboarded.

At the time of the accident the steam was on, and drying was in process. The building contained about 2100 pounds of compressed gunpowder blasting cartridges, distributed on 42 trays, on the racks, and 16 barrels of about 85 pounds each of grain powder cooling in the lobby or porch, the total amount of powder approximating 3,500 pounds.

The last person to enter the building was the stoveman at 1:30 in the afternoon. It was dark when the explosion occurred and no one was about, and there was no reason to suspect malice. The theory advanced was the heavy gale of wind may have blown the limb of a tree or some object on

the roof, and caused the explosion of an accumulation of powder dust on the old iron ceiling, which had been undisturbed for 36 years.

No one was killed or injured in this explosion. The building was completely destroyed, the heavy stones of which it was constructed being projected with tremendous violence in all directions and in some cases to long distances. The distribution of the debris took the form of a cross, the bombardment being the most marked toward the northwest, against the wind, in which direction heavy pieces were found 834 feet away. A second stream carried stones northeast 948 feet, and a third stream southeast extended 251 feet. This cruciform direction of the debris is used to show an advantage in placing danger buildings anglewise towards one another.

The scattering of these large blocks of stone must have been terribly fatal if the workpeople had been in the factory at the time, and as it was, further explosions were narrowly escaped, stones of great size and weight having fallen through the roof of some of the danger buildings, and lay among the powder therein. In the case of the charge house, 420 feet away, a stone 18 inches square which had passed through the roof was found on the floor, and in the case of the expense magazine, 228 feet distant, several stones, some of large size, had also entered through the roof.

Outside the factory, no damage was done except at Blackbeck Farm, 810 feet from the explosion, and about 30 feet higher and unscreened except by trees and slightly rising ground around the stove. Some glass and some framework of the windows of the farm were destroyed, and the slates of the barn lifted. The structural damage to the factory was as follows:

Building	Feet Distant	Extent of Damage
Fitting shop	387	Windows blown in.
Saw mills	345	Skylights blown in, slates lifted.
Mills	312	All mill fronts slightly blown out, one badly, with roof resting on runners.
Boiler house	251	Slates stripped off.
Box house	216	Ridging stripped off, east windows blown in.
Charge house	420	Window blown in, stone 18 inches square fallen through the roof.
Wagon house	375	3 or 4 sheets of roof loose.
Corning house	420	Windows broken on all sides door hinges broken. (Well protected by mound.)
Little engine house	221	South side slate roof stripped.
Glazing house	168	Windows blown in, doors off, 3 roof principals broken, roof dented in, boards sprung.
Expense magazine	228	Windows and doors broken, slate roof stripped, stones through roof.
Press house	322	Windows blown in, houses struck by stones.
Store house	147	Windows blown in, slates loose.
Dust and Packing house	231	Windows broken, slates off, boards sprung.

Light debris, consisting of small bits of slate, splintered wood, etc., was found in a continuous line for some 1680 feet due east, with the wind, curving round to the northeast.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Mills	Protected by location and by some mounds	Fronts blown out slightly, one badly, roof resting on runners	312
Area of structural damage.....			312 feet
Charted.....			312 feet
Missiles thrown, up to.....			948 feet
Glass broken, up to.....			810 feet

GIBBSTOWN, NEW JERSEY

Chart No. 83

An explosion occurred in the dry house at the Repauno Explosives Works, Gibbstown, N. J., on February 5th, 1908, at 4:15 A. M.

The explosion was caused by a fire in the nitro starch nitrating house. While the men were fighting the fire and playing the hose on this house, the flames caught the grass and spread the fire to the dry house, which contained 2000 pounds of partially dried nitro starch on trays, and 1500 pounds of dry nitro starch in boxes, making a total of 3500 pounds. This exploded within a half hour from the time when the fire was discovered in the nitrating house.

No one was killed or injured in this explosion. The origin of the fire was unknown, but one theory was that a suit of clothes hung on a nail over a radiator in the nitro starch nitrating house may have fallen on the radiator and caused the fire.

The force of the explosion was felt most severely in the vicinity of the Eastern laboratory, the old and new laboratories being particularly damaged. The packing house, the building nearest the nitro starch nitrating house, was not very badly damaged.

The structural damage was as follows:

Building	Feet Distant	Extent of Damage
Eastern laboratory	525	Windows and sash blown out, doors torn off, and considerable glass broken in the laboratory.
Nitro starch packing house	180	Crushed in so badly that the roof fell.
Brick magazine	250	Powder did not explode, but burned. Roof and one side torn off before it burned.
Nitro toluene plant	450	Rafters and collar beams split so that new roof was necessary.

Building	Feet Distant	Extent of Damage
O. V. Plant No. 2 (Buildings distant 550 to 750')		One side Pyrites shed blown down.
Burner house	550	Glass and window frames blown out and broken, roofs damaged.
Converter house	650	Same damage.
Absorber house	750	Same damage.
New motor house		Badly damaged nitro starch side.
New scrubber house	750	Windows broken.
Old scrubber house	750	South side torn out 6 inches from ground.
New nitro starch nitrating house	900	Windows and sash broken out and east end of building strained.
Refrigerating plant	850	Windows and door torn out.
Main power house	950	Glass and sash broken throughout.
Nitric acid recovery house	1400	Glass and sash broken, east and south sides.

Glass was broken in the soda dry house, in the main office and in the works laboratory.

Missiles were thrown as far as 1065 feet.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
O. V. Plant	No barrier	Roof and sides	700
Area of structural damage.....			700 feet
Charted.....			350 feet
Missiles thrown, up to.....			1065 feet
Glass broken, up to.....			several miles

ARDEER, SCOTLAND

Chart No. 138

An explosion occurred on an explosives factory at Ardeer, Ayrshire, Scotland, on January 9th, 1902, at 10:15 P. M.

The building in which the explosion occurred was one of a group of N.G. washing houses. It was lightly constructed of wood, protected on three sides by mounds of a more than usually substantial nature, the site being in part excavated from the natural sandhills.

The arrangement of the building was as follows: the two lead-lined washing tanks were raised about 8 feet above the floor on a wooden framework. In front of these, at a lower level, was the filter tank, while immediately below the washing tanks there was another large tank, which was kept continually full of water for the purpose of drowning the nitro-glycerin charges in cases of emergency. At the conclusion of the washing of each charge, it was necessary to remove the wash-water, before fresh

soda-solution or water was added to the washing tank, or before the nitro-glycerin was run into the filter tank. This was done by means of a skimmer, consisting of a metal funnel, the opening of which was permanently attached to a rubber tube leading to a gutter, whereby the wash-water was conveyed to another building. When not in use, the skimmer was supported well above the surface of the liquid by means of a cord passing over a pulley. When the wash-water was to be removed, this cord was released, and the skimmer was lowered and pressed beneath the surface of the liquid, so as to receive the water which, being lighter than the nitro-glycerin, had³ risen to the top. In some of the final washing houses a wooden stick was used for the purpose of pressing the skimmer below the surface but in this house a brass handle was fitted for this purpose. The skimmer was held in position by two rubber cords, with a view of preventing it from striking against the side of the tank.

At a little before 9 P. M., the chemist visited the final washing house, the building where the explosion later occurred, and found nothing unusual. Later on he instructed one of the nitroglycerin hands, a steady and experienced man, to shut off the compressed air in one of the other final washing houses at 10:07, and go to carry on the operation of washing in the house where the accident happened.

The explosion occurred at 10:15. Judging from the position of the fragments of the operator's body, and from the length of time that elapsed, it was thought that he must have been engaged in skimming off the soda solution from the top of tank No. 1, and that the most probable cause of the accident was the striking of the skimmer or its brass handle against the side of the lead-lined tank.

As is always the case with nitroglycerin, the explosion was one of very great violence. The building was of course completely demolished, the debris being scattered over a considerable area. The quantity of explosive present was 3582 pounds, of which 3400 was nitroglycerin and 182 pounds guncotton. Of the former there were 1650 pounds in each of the washing tanks, and about 100 pounds in the filter tank. The guncotton was in brass lined boxes in the body of the building.

No appreciable crater was formed in the ground on the site of the building, owing no doubt to the fact that the bulk of the explosive was raised high above the surface of the soil. The face of the mound at the back of the building was damaged and the mound showed a crack all along the top. The tunnel through which the gutter from the nitrating house passed, was formed of brickwork, and this was considerably shaken and cracked, some of the bricks having been blown off and projected some distance.

The buildings nearest the scene of the explosion suffered very severely,

although effectively screened. At the nitrating house, which was at a distance of 180 feet, the walls were sucked out, allowing the roof to drop. In two of the other filter houses, 195 and 180 feet distant respectively, the walls and roof on the side facing the explosion were stove in. Two other buildings at the same distance were damaged in much the same way. All these buildings were lightly constructed of wood, and their roofs were supported by the framework of the walls, so that they may be regarded as having been very vulnerable, especially so in the case of the nitrating house on account of its great height.

The small building used as a temporary deposit of explosives in transit, constructed of corrugated iron, was completely demolished, the sides and roof being sucked outwards and thrown to a little distance.

Less severe structural damage was done to buildings up to a distance of 510 feet, and beyond that a few doors were sprung open and window frames broken. In the Cunninghame poorhouse, and in the town of Irvine, each distant about a mile and a quarter, a large number of panes of glass were broken. In the latter place some very slight structural damage was complained of. In one shop it was stated that 300 eggs were broken, probably by falling glass. In a newspaper account it was stated that a large number of birds were killed by the explosion. Missiles were projected up to 120 feet.

Except for the operator, no one was killed or injured in this explosion.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Nitrating house	Barricaded	Walls sucked out, roof dropped	180
4 final washing houses	Barricaded	Roof and sides stove in	195
Less severe structural damage, up to.....			510 feet
Area of structural damage.....			510 feet
Charted.....			510 feet
Missiles thrown, up to.....			120 feet
Glass broken, up to.....			1¼ miles

ASHBURN, MISSOURI

Chart No. 3

On February 17th, 1906, at 2:45 P. M., an explosion occurred at the high explosives works located near Ashburn, Mo.

There were two explosions, separated by a perceptible interval of time, the first in the Hall cartridge machine house, and the second in the building known as No. 1 packing house. Both buildings were of frame construction.

Immediately behind the cartridge machine house was a steep hill, and No. 1, and No. 2 packing houses, about 40 feet in the clear on either side of the cartridge machine house, were protected by crib barricades. In front of the cartridge machine house, across the double tramway, was a crib or double-faced barricade, 3 feet 6 inches at the top, 7 feet 6 inches at the bottom, and 16 feet high. In front of the packing houses were storage sheds which could be considered as barricades.

At the time of the accident, the cartridge machine house was in operation. The packing houses had been abandoned as operating buildings when the machine house was put into operation, and were used only for storage.

In the cartridge machine house there were about 1500 pounds of 40% straight dynamite. The No. 2 packing house contained about 1200 pounds of damaged 40% gelatin explosives being thawed, and 1000 pounds of dynamite; in all 3700 pounds of explosives.

It is not known what caused the explosion. The cartridge machine house had been visited by a supervisor, foreman, and machine repairman within 15 minutes prior to the explosion, and everything was reported as running smoothly.

As a result of the explosion, the cartridge machine house and No. 2 packing house were entirely demolished, as were No. 1 packing house, the store sheds, heater house, etc.

The No. 3 packing house, 160 feet distant from the machine cartridge house, protected by the lay of the ground and barricades, was almost completely crushed in; every stud, 2 x 4 inches, and every rafter, 2 x 6 inches, being broken, the ceiling torn off, etc.

The dynamite mixing house, 200 feet distant and protected by barricades, was considerably damaged, as was also the hand packing house, distant 580 feet.

The safety buildings of the plant were across a ravine nearly opposite the cartridge machine house, at distances varying from 300 feet to 800 feet. The buildings within 400 feet—the ice house, general store house, etc.—were badly damaged. Of the others, many trusses and rafters were broken, and in the brick buildings the brickwork was started at the eaves and gables. All windows were broken throughout the area. The limit of structural damage was about 580 feet.

On the nitroglycerin line, located in the ravine about 700 feet away, and the gelatin line, 900 to 1000 feet distant, protected by the lay of the ground, there was practically no damage of a structural nature. In other parts of the factory there was hardly any damage except broken windows.

The three men working in the cartridge machine house were killed. Five men in No. 3 packing house escaped with only slight injuries, although

it was some time before they were able to extricate themselves from the wreckage of the building. There were no other persons injured, except for slight cuts from flying glass.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Buildings in safety area	Artificial barricades	Studs and rafters broken, brickwork damaged	580
Area of structural damage.....			580 feet
Charted.....			580 feet
Missiles thrown, up to.....			no record
Glass broken, up to.....			1560 feet

WALTHAM ABBEY, ENGLAND

Chart No. 113

A severe explosion occurred at the Government Cordite Factory, at Waltham Abbey, England, on May 7th, 1894, at 4:08 P. M.

The explosion occurred in the wash house and involved the nitroglycerin store house, 183 feet distant. These buildings were wooden structures with tarred felt roofs, each one being surrounded on all sides by high brick-revetted earth traverses.

In the wash house was carried out the final washing and purification to test of the nitroglycerin, and filtration of the purified material, which was then run down a V-shaped leaden gutter in a wooden tunnel to the nitroglycerin store. Here the nitroglycerin was stored and weighed out into charges, which were poured on to weighed charges of gun cotton, preparatory to removal for incorporation.

In reality there were two explosions so nearly simultaneous as to have led many persons who were near the spot to believe that only one had actually occurred, while those witnesses who heard the two testified to their having succeeded each other at an almost inappreciably short interval.

The quantity of nitroglycerin present in the washing house at the time of the explosion was about 1500 pounds; in the nitroglycerin store there was about 2200 pounds. The total quantity which exploded was therefore about 3700 pounds.

It was not possible to say positively to which of the various possible causes the accident was due, but it was considered that it was most probably among four special risks, as follows:

Risk from a blow or friction from the fall or violent movement of the leaden skimmer.

Risk from the use of earthenware cocks.

Risk from friction established by the leaden air pipe.

Risk from the fall or use of some article commonly present in the washing house.

The falling glass and debris from the roofs cracked and broke a number of the earthenware nitrating pots in the neighboring gun cotton factory, and admitted the water to the guncotton in process of digestion in the acids, causing them to fume off.

In the nitroglycerin factory, a quantity of this liquid in process of separation in No. 2 nitrating house had a narrow escape, as the building was considerably injured, and debris fell into the separating tank. Fortunately none of the debris was wood or of a carbonaceous character, otherwise this charge would have exploded.

The cordite factory, which was distinct from the nitroglycerin factory, was situated 180 to 900 feet from the explosion, and although the buildings were greatly shattered, the cordite did not take fire or explode.

The gun cotton stove, distant 255 feet, a building used for drying cordite, containing 3000 pounds of that material in process of drying by hot air, was completely crushed and broken up by the explosion, but none of the cordite was even ignited.

There was serious injury to substantial walls at 285 feet, and injury to weak buildings, breakage of doors, window sashes, etc., at 2700 feet.

In this explosion four men were killed, and 20 persons were injured, some of them as far distant as 900 feet.

Heavy debris was projected 2100 feet.

Light debris, with the wind, was projected 1950 feet.

Light debris against the wind was projected 360 feet.

Windows were broken up to two miles and a half.

It should be noted that the extreme range of projected debris, 2100 feet, was produced by a charge not exceeding 2200 pounds of nitroglycerin, say 2933 pounds of No. 1 dynamite. The extreme danger range as regards damage to weak structures was 2700 feet; but the two explosions were almost simultaneous, and consequently, for concussive effect, their sum, or 3700 pounds of nitroglycerin, or 5067 pounds of No. 1 dynamite, should be regarded as the cause of the damage. Two concussions, each of equal force, and almost simultaneous, would produce a greater effect than a single explosion of the total quantity.

For example, if the pressure at any distance from the first explosion produce a deflection in a yielding substance, surface or structure, and the pressure from the second explosion be received before the deflected substance, surface or structure, has time to return to its original position, it is

evident that the second pressure acts at a moment when the maximum amount of damage is possible.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Substantial buildings	Barricaded	Seriously damaged	285
Weak buildings	Barricaded	Breakage of doors, window sashes, etc.	2700
Area of structural damage.....			285 feet
Charted.....			285 feet
Missiles thrown, up to.....			2100 feet
Glass broken, up to.....			2½ miles

ARDEER PLANT, AYRSHIRE, SCOTLAND

Chart No. 140

An explosion occurred on the explosives factory at Ardeer, Scotland, on October 7th, 1902, at 5:25 P. M.

The building in which the explosion occurred was one of the nitroglycerin final wash or filter houses, lightly constructed of wood, and screened on three sides by substantial mounds and high sand hills. The site of the building had been prepared by excavation in these sand hills.

The explosion took place just after the two night men came on duty at 5:00 P. M. to make the rounds of the wash houses. From the evidence of the other man, the operator in the building where the explosion occurred, could have been there only four or five minutes. In the usual course of things, on arriving at the house he would change his shoes, and then look at the board on which he would find the particulars as to the treatment of the charges to be pursued by him. He would then proceed to skim the first tank. The process of skimming took from three to three and a half minutes from the commencement till the time of turning on the air preparatory to running in the next lot of wash water. There can be little doubt then that he was either skimming the first tank or turning on the air.

It was believed that the most probable cause of the accident was by the operation of turning on the air. The lead pipes through which the air is forced into the nitroglycerin in the tank lie loosely on the bottom of the tank and are supplied by a main air pipe which passes up the inside of the tank, and away to the wall of the house, through which it passes to a compressed air reservoir outside. These pipes are in no way connected to the lining of the tank, and would probably have become roughened with sulphate and lime. Such roughening of the surface, and the possible presence of sand or grit at the bottom of the tank would seem to provide sufficient

friction to fire a very minute film of nitroglycerin in proximity to the bearing surfaces, or even a slight blow might be delivered by the trembling pipes.

The amount of explosives present at the time of the accident in the building was 4,000 pounds of nitroglycerin and nitro-cotton.

Only one man, the operator in the final wash house, was killed in this explosion, and no one was injured.

The structural damage done was as follows:

Building	Feet Distant	Extent of Damage
Wooden construction	455	Roof lifted off badly, wall sucked out, house shifted at base; doors forced open and broken. Gable forced in.
Wooden construction	330	Gable badly forced in, wall plates broken, 2 windows driven in, 2 sucked out. Side wall partly out, much glass broken.
Wooden construction	265	Side partially sucked out, all glass broken, roof forced partially down, roof beam broken.
Corrugated iron and wooden construction	110	Demolished.
Wooden construction	165	One side completely smashed in, one side roof smashed; all glass broken.
Wooden construction	450	Lower part of roof spars all broken. Gable sucked out, broken standards. Windows driven in, back partially forced in. Porch partially sucked out, much glass out.
Wooden construction	600	Gable and porch side slightly sucked out, glass broken.
Wooden construction	500	Side partially stove in.
Wooden construction	515	Gable sucked out slightly. One side slightly forced in. Much glass broken.
Wooden construction	620	Porch side partially sucked out, gable slightly sprung. Windows on one side driven in, glass broken.
Wooden construction	755	Damage slight.
Wooden construction	285	Gable driven in, door posts broken, windows driven in. Roof spars split, porch standards broken.
Wooden construction	215	Badly damaged, back and front stove in, also roof. Doors broken off, all glass broken.
Wooden construction	340	Front partially driven in, windows driven in, all glass broken in front, porch standards broken, doors driven in.
Wooden construction	275	Front stove in, one window driven in. Porch ends, boards and standards broken. Steam pipe broken at heaters.
Wooden construction	430	Front driven in, wall plate broken. Porch sucked out partially, standards broken.

In addition to this list of structural damage, many wooden buildings, and buildings of brick and slate, and corrugated iron, received minor injuries, at distances from 380 feet to 2230 feet.

Missiles were thrown to a distance of 645 feet. Pieces of lead gutter and pipe were thrown 549 feet, and pieces of the soda tank were thrown 50 feet, while pieces of lead flooring were found 564 feet away.

Glass was broken to a distance of 2230 feet.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Wooden buildings	Barricaded	Walls and roofs damaged. Shifted on foundations. Porch sides knocked out, gables sprung	455 to 500 feet, on an average
Area of structural damage.....			500 feet
Charted.....			500 feet
Missiles thrown, up to.....			645 feet
Glass broken, up to.....			2230 feet

ISHPEMING, MICHIGAN

Chart No. 1

On August 25th, 1905, an explosion occurred in the Anthony Powder Works, located between Ishpeming and Negaunee, Michigan. The main buildings of the works, which included four separate structures known as the mixing, packing, nitroglycerin, and engine houses, were destroyed. The explosion occurred about 8:15 P. M., and the only person on the premises, after the employees had departed at 6 o'clock, was the night watchman, who escaped as soon as he noticed the fire in the mixing house.

The trouble started in the mixing house, where nitrate of soda was being prepared for the operations the next day, and the supposition is that the framework of the building was ignited from overheated nitrate of soda. The flames traveled from the mixing house to the packing house, located about fifty yards away, by means of a covered passageway which connected the two buildings.

The nitroglycerin house, situated on a ledge of rock about 25 yards from the mixing house, was next attacked by the flames, and the 4100 pounds of nitroglycerin in the building exploded as soon as it was reached by the fire.

Four explosions took place, following each other several minutes apart. The first three were of minor importance, and the last one was the 4100 pounds of nitroglycerin.

A storage magazine 600 feet distant from the nitroglycerin house, and unprotected, was badly shattered, and many of the boxes containing powder were broken and the powder scattered over the floor. This magazine contained 15,000 pounds of dynamite.

There were a few minor buildings such as storehouses and barns distant about 1500 feet from the nitroglycerin house. The walls of the barns were pulled out, and the roof partially fallen in. The windows facing the explosion were all broken, while those on the opposite side were intact.

Large plate glass and other windows were broken in Ishpeming, 2½ miles away. A school building half a mile from the works had only six windows broken, while another school house 2½ miles distant had twenty-six windows broken.

Large boulders were thrown 600 feet, and small stones and building materials were hurled 3750 feet.

The explosion was felt in Ishpeming more severely than at Neguanee, owing to the fact that a series of hills were between Neguanee and the explosion, while in the direction of Ishpeming only one hill intervened.

The country in the vicinity of the works was rolling and partly wooded.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Storage magazine	No barrier	Badly Shattered	600
Storehouses and barns	No barrier	Walls slant, and roofs partly fallen in	1500
Area of structural damage.....			1500 feet
Charted.....			750 feet
Missiles thrown, up to.....			3750 feet
Glass broken, up to.....			2½ miles

ARDEER, SCOTLAND

Chart No. 170

An explosion occurred on the factory at Ardeer, Ayrshire, Scotland, on February 20th, 1914, at 10.07 A. M.

The building in which the explosion occurred was one in which the operation of incorporating the ingredients of gelatinous nitroglycerin was carried out. Its dimensions were 25 by 43 feet, and it was lightly constructed of wood, barricaded by mounds. There were eight incorporating machines in this building, the charges for which were either undergoing the process of mixing, or standing in boxes ready for introduction into the machines. There was also a quantity of nitro-cotton in a special compartment for weighing out charges for the filter house.

The amount of explosive present was estimated at 2120 pounds of blasting gelatin, 1760 pounds of nitroglycerin and nitro-cotton mixed, and 300 pounds of nitro-cotton, making a total of 4180 pounds.

The incorporating machine employed at Ardeer consisted of two vertical revolving gunmetal spindles, each of which carries 12 horizontal blades in three sets of four, there being ample clearance between the ends of the blades and the sides of the pan containing the explosive. This brass pan rests on the floor during the operation of charging, but is free to slide horizontally into position under the spindles, and can then be raised by rack and pinion until the blades of the spindles are in the correct position for mixing, stop-blocks being fitted to prevent the ends of the spindles from coming into contact with the bottom of the pan. The sides of the pan are made double so as to form a jacket to contain water, at a temperature of 140° Fahr. to 149° Fahr.

At the time of the accident four of the machines were running on paste for blasting gelatin, and the other four were in the various stages of loading, their late charges being in the course of removal by runners. Work may also have been going on in weighing nitro-cotton.

Thus the explosion could not have occurred at a more unfortunate moment. The seven men, five workers and two runners, present in the building at the time were instantly killed, and an eighth man, a runner, was so seriously injured that he died. Two other runners were injured, one seriously.

The cause of the accident was thought to be some circumstance in connection with the charging of a machine. The only loose article which could possibly fall into a machine during the operation of loading would be the thin sheet lead apron employed for the purpose of preventing spillage during the transfer of the thin jelly from box to pan. The leaden apron may have been allowed to fall into the pan of a machine, may have been caught between the revolving stirrers, and crumpled up, causing the blades to foul one another. The stress may have been sufficient to break one of the spindles.

The building in which the explosion occurred was completely obliterated leaving a series of small craters. The heavy machinery, of which the building contained a large quantity, was thrown all over the factory, one piece of stirrer-blade being found at a distance of over 3000 feet, and others at distances from 1500 to 2100 feet, while a piece of the gunmetal shaft of a stirrer was picked up 5100 feet away.

A laboratory magazine, 390 feet to the south, containing 609 pounds of blasting and propulsive explosives, was seen to be burning for several moments before it exploded. It is thought that ignition was caused by

a piece of machinery or other debris from the gelatin mixing house, and that after burning for a minute or two the fire reached the bulk of explosive material. No life was lost by this explosion.

Practically every building within a radius of 546 feet of the gelatin incorporating house suffered structural damage, 37 buildings needed partial reconstruction, and between 90 and 100 buildings in addition needed repairs, exclusive of those in which only glass was broken.

The damage outside the area of the factory was limited to broken glass in the Ardeer Iron Foundry, a mile and a half distant, injury to school house walls, and glass breakage at Dalry, six miles away.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
37 out of 47 plant buildings	Artificial barricade	Needed partial reconstruction	546
Area of structural damage.....			546 feet
Charted.....			546 feet
Missiles thrown, up to.....			3000 feet
Glass broken, up to.....			6 miles

BARKSDALE, WISCONSIN

Chart No. 8

There was an explosion in the No. 2 nitroglycerin storehouse at the high explosive works at Barksdale, Wis., on October 24th, 1907, at 6:50 A. M.

The No. 2 nitroglycerin storehouse was a frame structure, surrounded with double-faced or crib barricades, earth-filled.

About the time of the accident, the nitroglycerin wheeler was evidently drawing off a charge of nitroglycerin preparatory to taking it to the mixing house for the first mixing of the day. The storehouse contained, at the time, 4210 pounds of nitroglycerin.

No probable cause for the accident could be advanced.

As a result of the explosion, the nitroglycerin storehouse was destroyed, and the No. 2 mixing house, 100 feet distant, and provided with a double-faced or crib earth-filled barricade at the back and on the sides was completely wrecked; in fact, so badly damaged it was necessary to tear the house down and rebuild.

The No. 1 mixing house, distant about 220 feet and protected with barricades, had the roof lifted and gable end in the direction of the explosion torn out; some of the roof timbers were broken, and the ceiling badly damaged.

The No. 1 nitroglycerin storehouse, 220 feet away and protected by barricades, had the walls and roof pulled apart; the damage being suffi-

ciently serious to necessitate new roofing.

The dope house, 330 feet distant, protected only by the barricade at the No. 2 nitroglycerin storehouse, was but slightly damaged.

The No. 3 cartridge house, 470 feet distant, protected by a barricade, was quite badly shaken and a portion of the ceiling broken.

The No. 1 cartridge house, also protected by a barricade. 500 feet distant, had the shed over the tram track blown down. The roof and sides of the house were in weakened condition. The machine in the house was completely out of alignment.

The No. 1 neutralizing house, 540 feet distant, and surrounded by barricades, had only windows broken. The No. 2 neutralizing house, 640 feet distant, also barricaded, in addition to breakage of windows, was severely shaken, with but slight damage.

Other buildings on the nitroglycerin and powder lines, at distances between 700 to 1200 feet from the explosion, only had windows broken.

The nitroglycerin wheeler and two mixing house operators, who happened to be in the No. 2 nitroglycerin storehouse at the time of the explosion, were killed. A third mixing house man left this building a few moments before the explosion, and was between the nitroglycerin storehouse and the mixing house when the nitroglycerin exploded. He was blown 10 or 12 feet off the walk, but got up and ran about 75 feet before he collapsed. The upper part of his left leg was severely, but not permanently, injured. The presence of the mixing house men in the nitroglycerin storehouse was due to the fact that they were in the habit of changing their clothes in that building, as warm water was available, although this practice was against the rules.

There were three men injured, two were cut by glass, and the third was thrown against the machine in No. 3 cartridge house and suffered a broken collarbone.

The missiles projected by the explosion consisted of stones, which had been carelessly left with the earth used to fill the barricades. These were thrown 1000 feet.

Breakage of glass occurred in the safety area up to 1500 feet from the scene of the explosion.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Cartridge house	Artificial barricade	Shed over tramway blown out. Roof and sides in weakened condition	500
Area of structural damage.....			500 feet
Charted.....			500 feet
Missiles.....			1000 feet
Glass broken (frequent).....			1500 feet

LOUVIERS, COLORADO

Chart No. 66

An explosion occurred at the explosives works, Louviers, Colorado, on June 20th, 1908, at 10:30 A. M., in the nitroglycerin neutralizing house. This building was barricaded.

At the time of the explosion, it contained 4400 pounds of nitroglycerin. The first charge of the day had been neutralized. Of the second charge, the top half had been separated off, washed in the separating house, and run by gutter into a tank in the neutralizing house, which had been washed out that morning. This tank contained only some clear warm water, which had been run into it before the half charge was run from the separating house, and as nearly as can be determined the temperature of this water was about 110°F. when it left the separating house, and was probably not over 90°F. in the neutralizing house. The nitroglycerin was followed by a soda solution, containing about 25 pounds of soda ash, and the temperature of this when it left the separating house was 115°F. The soda solution had just about time enough to reach the neutralizing house when the explosion occurred.

The line foreman had just visited the neutralizing house. If anything had been wrong there, he would have noticed it. He had just left the building and was on his way to the gelatin line nitroglycerin storehouse when the explosion occurred. The cause is unknown.

The operator in the neutralizing house was killed, and one other man was injured, but only from a fall.

The principal structural damage was done to the separating house and the two storehouses.

Half the roof of the separating house, 250 feet distant from the explosion, was pushed down about 4 feet, and the walls badly drawn in. Several pieces of sticks were dropped into the separator.

Nitroglycerin storehouse No. 1, 300 feet distant, had windows and sash broken, and the roof of the wing sprung.

Nitroglycerin storehouse No. 2, 350 feet distant, had windows broken, walls sprung, and the roof of the wing raised 4 inches.

Gelatin mixing house No. 2, 625 feet distant, had windows and sash gone, roof opened about one inch.

The dope house, 625 feet distant, had broken windows and some corrugated iron displaced.

Missiles were thrown 1500 feet. Glass breakage was within a mile.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Dope house	Barricaded	Roof damaged	625

SUMMARY, Continued

Area of structural damage.....	625 feet
Charted.....	625 feet
Missiles thrown, up to.....	1500 feet
Glass broken, up to.....	Within a mile

PINAR DEL RIO, CUBA

Chart No. 148

An explosion which caused much loss of life occurred at Pinar del Rio, Cuba, at 5 o'clock P. M., on May 18th, 1910.

Owing to race disturbances, the dynamite being used for road-making and various public works in that section of Cuba, had been collected and stored in the barracks at Pinar del Rio, an old Spanish building of massive construction which stood on a hill on the outskirts of the city to the north. This building was occupied in part by the Public Works employees and by the Rural Guard, and families of officers.

Orders had been given for the removal of the explosives to powder magazines, and it was while this was being attempted that the explosion occurred. About 1500 pounds of powder, which had been left by the Spanish Government several years before, exploded, and caused the wall of the room to fall on 3000 pounds of 40% dynamite stored in the next room. This in turn exploded, wrecking the building completely. It was estimated that 20 seconds intervened between the first and second explosions.

There were 47 people killed, 36 men, 7 women, and 4 children; and 115 people were injured.

Most of the men killed were members of the rural guard. The commandant and all his family were killed. Intense excitement reigned both at Havana and Pinar del Rio, as the rumor started that the explosion was the first overt work of revolutionists. It was said that May 18th had been set for the uprising, the earth that day entering the tail of Halley's comet. Special trains carrying troops were rushed from Havana to Pinar del Rio.

The real cause of the explosion was not definitely known. The workmen who were loading the powder on carts to remove it to the regular powder magazines were said to have been very careless, smoking while handling the explosives, and throwing matches and cigarette butts on the floor of the storehouse. The powder was put up in heavy wooden zinc-lined boxes, each box holding 100 pounds. The boxes were damaged, and leaking powder. The storekeeper, who was fatally injured, but who lived two days after the explosion, said that a carpenter was repairing the powder boxes at the time, and he thought that driving nails in the lids set the powder off.

The whole front of the barracks in which the accident occurred was

torn out, and about 80 feet on one side.

A frame building 140 feet distant was completely demolished.

A frame building 240 feet distant had one side destroyed.

A store 260 feet distant had the side and roof badly damaged.

Some tenant houses 160 to 320 feet distant had roofs caved in and front walls gone.

A store 300 feet distant had doors and windows on town side blown out.

The Spanish Club, $\frac{3}{8}$ of a mile distant, had all doors and windows on two sides blown out.

The Palace of Justice, in course of construction, $\frac{1}{2}$ mile distant, had the window sash blown in on side toward the explosion.

Missiles were blown $\frac{3}{4}$ of a mile. Fragments of masonry of the barracks were dropped on the northern section of the town.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Tenant houses	No barricade	Roofs caved in, front walls gone	320
Area of structural damage.....			320 feet
Charted.....			160 feet
Missiles thrown, up to.....			$\frac{3}{4}$ mile
Glass broken, up to.....			No record

HASKELL, OKLAHOMA

Chart No. 167

An explosion took place in the "Torpedo" nitroglycerin works at Haskell, Oklahoma, at about 4:30 P. M., on June 30th, 1912.

The explosion occurred in the canning room. Five runs of 850 quarts of nitroglycerin had been canned, and the sixth run, 170 quarts, was in the wash tank, and this, with 410 quarts stored in the canning house at the time, made a total of 1430 quarts, or 4648 pounds.

The assistant maker had dumped the acid into the nitrator for the seventh run. The glycerin had not yet been started. He had gone into the boiler house to fire up, and had just taken a shovelful of coal, when the explosion took place. The nitroglycerin maker had just gone into the canning house, and was killed instantly.

The assistant nitroglycerin maker in the boiler house, 50 or 60 feet from the explosion, was injured quite badly. The boiler house fell on him, but did not hold him fast, and he got out before the steam or hot water reached him; but he received some severe bruises, and fractured a wrist and an ankle. There was a pile of cinders about 4 feet high, between him and

the factory, and the force of the explosion shot his head and body full of cinders.

The cause of the explosion was not known, and the only explanation suggested was that the wash water might have been too hot.

No one else on the plant was injured, but a man in a dwelling 500 feet away was thrown from a cot and bruised as a result of the explosion.

The plant was entirely wrecked. There were no barricades, but a thick grove of trees was considered as affording protection.

A brick building 550 feet distant had the roof damaged and the brick wall bulged.

A frame building 1900 feet distant had the window frames broken and some plaster knocked off and glass broken.

Missiles were thrown 2640 feet, and glass was broken in the town of Haskell, about 3 miles from the plant. A pair of horses 50 feet away, escaped uninjured, although the buggy to which they were hitched was badly smashed.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Brick dwelling	Trees	Roof damaged, brick wall bulged	550
Area of structural damage.....			550 feet
Charted.....			550 feet
Missiles thrown, up to.....			2640 feet
Glass broken, up to.....			3 miles

FURNACE, LOCHFYNE, SCOTLAND

Chart No. 129

There was an explosion in the gunpowder factory at Furnace, Lochfyne Scotland, at 3:10 P. M., on Saturday afternoon, September 29th, 1883.

The stove or drying house in which the accident occurred had two compartments, one the "drying" part, which was of stone, 20 feet wide, and the other the "cooling" part, which was of brick, about 8 feet wide. The latter was the side toward the mound. Both compartments were under one roof, which was of slate, and together formed a building measuring about 30 to 33 feet square. There were two doors, one to each compartment, both being entered from a platform covered by a porch on the northeast side. Some of the stones forming the walls of the drying part, which were about two feet thick, weighed over two hundredweight. The building was not barricaded.

The drying part was heated by an iron steam pipe 10 inches in external diameter, with a thickness of metal about one-half inch. The steam pipe

entered the building near the top, passed down at one corner to a little below the floor level, and thence around the interior in a trough, being supported on small pieces of wood. The trough was uncovered except at the doorway, but canvas trays, about two feet wide, on which the gunpowder was dried, were arranged one above another all around the building over the uncovered part, concealing the steam pipe from view. No powder was dried on the lowest tier of trays, but doubtless some of it fell through the trays and into the trough below, and on the steam pipe.

The steam for drying was generated in a boiler in a small brick boiler house about 20 feet from the drying part of the house. The safety valve was set to blow off at 15 pounds and the ordinary pressure in the boiler was from 8 to 10 pounds per square inch.

The explosion occurred about ten minutes past three o'clock. As the factory was closed at 2 P. M. on Saturdays, the ordinary work was over for the week; but in the heading-up house, three men and a boy were still employed in packing some gunpowder intended to be shipped that afternoon. There were also six other workmen in the factory, but no one was within 240 feet of the drying house when the accident happened.

The drying part of the house in the morning had been charged with 5000 pounds of corned powder, and this was the only powder in the building. Charging was completed about nine o'clock in the morning. The heater attendant had visited the boiler house at intervals, his last visit having been made about 2 P. M.

The cause of the explosion was not known, but it was probably due to powder on the steam pipes in the drying house igniting.

The immediate effect of the explosion was to project with great force the stones composing the walls of the drying part in four directions, at right angles to the four faces of the building. One stone weighing 250 pounds was found at a distance of 900 feet, and smaller stones weighing 5 pounds and under were scattered up to 1350 feet. Several large stones fell through the roof of a cottage without injuring the two persons in the house. The distribution of the stones was quite general and far-reaching but comparatively few stones fell out of the four lines of fire. Considering the large number of stones which were projected, it was little short of a miracle that the loss of life and personal injury were so slight. The manager, who was at his home standing with his back towards the explosion, was struck by a large stone which carried away one of his legs and broke the other in two places, afterwards knocking down the wall on his son, who was injured but not seriously. The manager lingered for about two hours but never regained consciousness. A woman was struck by a stone in a dwelling house and was injured on the right arm and head. The foreman of the factory, who was

repairing a pipe near the press house, 468 feet away, was thrown some distance by the force of the explosion and sustained a slight injury in his back. No one else appears to have been injured in any way. Two horses in a stable were struck by stones, and one of them died soon afterwards.

The damage to the buildings of the factory was not as great as it might have been. Although all the danger buildings contained more or less gunpowder, the explosion was not communicated to any one of them. Their escape was doubtless to a great extent due to the direction of the wind at the time, since the factory was excessively congested. Also the factory was in a poor location as regards the highway and the neighboring village.

The structural damage to buildings outside, 800 feet to 1600 feet, consisted mainly of holes made through the roofs by stones, doors and window frames blown in, and plaster detached from ceilings.

Several panes of glass were broken in a church 3000 feet away, and a few panes of glass were also broken in cottages up to a mile.

The list below indicates the damage sustained by the principal buildings of the factory:

The stove or drying house and boiler house were entirely razed, including the foundations. The boiler, nearly uninjured, remained resting on some bricks. The mound was shaken but stood well, and many stones and a large mass of barrel hoops and staves were caught by it.

The dusting house, distant 162 feet, had little damage done to its walls, except in one gable. The roof was broken in at one end, and slates were gone in other parts. The wooden lining prevented a stone, which passed through the roof, from falling into the building. The windows were all gone, and the door forced inwards. The porch was gone, except the supports and roof. This building contained about 1000 pounds of finished gunpowder.

The glazing house and pump shed, 312 feet distant, had the southwest end of the building, walls and roof, much damaged by stones, and the pump shed completely gone. The porch and door were gone, and seven windows were smashed in. A piece of steam pipe of the stove, about 3 feet 6 inches long and 10 inches in diameter, weighing nearly 100 pounds, was blown through the roof, making two holes. The roof was also damaged by stones. The glazers, which were running at the time, were not stopped by the explosion; they contained about 4300 pounds of gunpowder, and there was also about 900 pounds in tubs in this house.

The press house, 468 feet away, suffered very slight structural damage, merely displacement of woodwork, fracture of the door, etc. About half of the glass, 120 panes, was broken. This building contained about 1200 pounds of mill cake, the press being partly full. A large stone weighing over 50 pounds went through the porch.

The corning house, 416 feet away, sustained no damage except to



- 1 Site of Explosion
- 2 Freight Station
- 3 Pile of Lumber
- 4 Small House
- 5 P.C.R. Depot
- 6 Small R.R. Building
- 7 Brick Residence
- 8 Lumber Dry House
- 9 Pile of Logs
- 10 Lumber Mill
- 11 Location of House and Wagon
- 12 Lumber Store House
- 13 Small Frame House
- 14 Small Frame House
- 15 Row of Small Houses
- 16 House Barn and Sheds
- 17 Frame House
- 18 Elevator and Planning Mill

- 19 Frame House, Two Story
- 20 Two Story Residence
- 21 Two Story Residence
- 22 Two Story Residence
- 23 Frame House
- 24 Bedrooms of Workmen's body frame
- 25 Frame Dwelling
- 26 Frame Dwelling
- 27 Brick Residence
- 28 Carriage Factory
- 29 Frame Tractors
- 30 Old Bus Car used for shed
- 31 Dressing and Saw Mill
- 32 Dressing and Saw Mill
- 33 Building on Main Street
- 34 Building on Main Street
- 35 Buildings on Main Street
- 36 Methodist Church
- 37 Ring Ground

ESSEX, ONT. EXPLOSION August, 10th 1907

porch and doors and windows. There were 1500 pounds of press cake and dust in this building. All the panes of glass in five windows were broken.

The store for kegs, 235 feet distant, had part of one wall blown down, the roof fallen in, and windows broken.

The store for kegs and heading-up house, 234 feet distant, was very little damaged, being protected by the store for kegs at the side. Three men and a boy were engaged in packing gunpowder in this building, which contained about 3800 pounds of gunpowder, 3000 pounds of which was packed ready for removal. No one in this building was injured.

The expense magazine, 260 feet away, had its door forced open outwards, and the wood cover to the brick-arched roof slightly damaged. The house contained from 6000 to 7000 pounds of finished gunpowder, unpacked.

The expense magazine, 416 feet away, had its door forced open inwards, and the roof a little damaged. The house contained about 1400 pounds of finished gunpowder, unpacked.

The factory magazine, 624 feet distant, had its two doors forced open by the explosion, one being a little cracked and the footboards slightly dislodged. It contained about 46,000 pounds of gunpowder.

The mills, 880 feet distant, sustained no damage except the displacement of some corrugated iron roofing.

The mixing house and non-danger buildings, 468 feet distant, sustained generally but very little damage, beyond the breaking of windows and forcing open of doors. A large stone went through the roof of a watch house.

Glass was broken to about one mile from the explosion.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Keg store	No barricade	Roof fallen in, walls blown down	235
Area of structural damage.....			235 feet
Charted.....			118 feet
Missiles thrown, up to.....			1350 feet
Glass broken, up to.....			1 mile

ESSEX, ONTARIO

Chart No. 38

Saturday noon, August 10th, 1907, a dynamite explosion occurred at Essex, Ontario, Canada, with loss of life and great damage to property.

Essex was a rather compact and well-built village of about 1,400 people, located on the Michigan Central Railroad about 17 miles from Windsor. A branch of the Michigan Central runs from Essex to Amherstburg, Ontario,

the latter point having some quarries, and being headquarters for the very extensive dredging work being done on the Detroit River.

The fact that the day following the explosion was Sunday brought a great concourse of people to the little town, probably 10,000 during the day, which made investigation difficult. The sketch of the location of the accident, attached, covers all of the town which was seriously affected by the explosion. Glass was broken, plastering tumbled down, and dishes and ornaments displaced over a wide area, but the serious damage all occurred within the radius covered by the plan.

The exact time of the accident was 9:47 A. M., Eastern time. This was shown by the stoppage of numerous clocks.

The best information obtainable indicated that the car held 100 boxes or 5,000 pounds of 60% nitroglycerin dynamite, shipped by the Pluto Powder Company to the Dunbar and Sullivan Dredging Company, Amherstburg, Ontario, and billed as powder cartridges. The day operator of the Michigan Central advised that one of the brakemen said that in one end of the car was a quantity of groceries, chiefly canned goods. Numerous broken cans were found in the vicinity, one or two of which held part of their contents, chiefly "Green Peas." There is no reason to believe that any caps or fuzes were in the car.

It was universally claimed at Essex that the explosion occurred through leakage of nitroglycerin on to the railroad tracks.

There was only one train a day to Amherstburg, leaving Essex at 10:45 A. M. The car containing the dynamite arrived on Friday, too late for the Friday train to Amherstburg, and accordingly lay in the yard awaiting the Saturday train.

This train when handling dynamite was made up as follows: the dynamite car was attached to the engine tender and followed by miscellaneous freight cars, the single passenger coach being attached to the last freight car.

The claim was made that leakage from the dynamite car was noticed early Saturday morning or on Friday afternoon. This was called to the attention of the brakeman, who proceeded on Saturday morning to couple the car to the engine, preliminary to making up the Amherstburg local as above described. Before the car was actually moved, the door was opened and the freight inspected. The brakeman is reported to have found the dynamite boxes in more or less confusion, apparently due to imperfect loading or handling when inspected, or to some rough treatment en route.

The conductor claimed to have reported the bad condition of the dynamite to the station agent. There were about 100 boxes, some piled on top of each other, and others standing alone, and the conductor assisted in turning some of the boxes around, thinking that this would stop the leak-

ing. The car was then closed, this being between 15 and 30 minutes before the explosion occurred. The best information obtainable indicated that there were several small explosions on the track during the making up of the local, and that the final explosion came without any warning, and at a time when a brakeman was looking under the car trying to locate the exact point where the nitroglycerin was leaking through the bottom of the car.

Two brakemen were killed outright by the explosion. The body of one was driven partly into the ground under the next car, and was not as badly mutilated as would be expected. The other man was evidently standing on the north side of the car, where he got the full force of the explosion, and fragments of the body were found between 25 and 500 feet north of the explosion.

The newspapers stated, universally, that a doctor who was ill at his home died soon after the explosion, as a result of the shock. There was no foundation for this report, as the apothecary, who was familiar with the case, stated that the patient was delirious for hours before the explosion and did not recover his senses up to the time of his death, early Saturday afternoon. It was the opinion of the physician that he did not know of the explosion, or feel it in any manner. His house was probably a quarter of a mile from the car, and suffered no damage apparent from the outside but broken glass.

Among the persons seriously injured were:

The station agent, stunned, and cut in a number of places. His recovery was considered doubtful at first.

The engineer on the Amherstburg train was jammed in cab of the engine, and severely bruised.

The conductor on the Amherstburg train had cuts sewed up in seven places, and suffered severely from shock.

The watchman at round-house, the acting fireman of the train, had large scalp wounds, and his shoulder and right side injured.

The day telegraph operator was more or less cut, but suffered chiefly from shock.

A grain merchant in Amherstburg was struck by a falling iron brace and severely hurt.

Not less than 50 people sustained minor injuries, cut by falling glass or bruised by falling woodwork, debris or plastering. The wife of the station agent was quite badly cut by falling timbers in her house, at least 600 feet from the car. Narrow escapes from death, or serious injury were innumerable.

A boy walking across the track about 400 feet in front of the engine was blown quite a little distance, somewhat bruised and rendered insensible for a minute or two. The top of his hat was completely cut off by an air current or some falling fragment.

A workman in the lumber mill 200 feet away was saved from death by following the directions of his employer given the day before to pile certain pieces of timber on end instead of flat on the ground, as was his custom. This formed a support for the roof, which otherwise would have crushed him.

A negro woman with a baby in her arms on the station platform about 300 feet away, was knocked down and somewhat cut by falling pieces of wood, but the child was absolutely unharmed.

One of the fast trains from Chicago to New York, ordinarily carrying several hundred passengers, was due at the station exactly two minutes before the explosion occurred. This train was fortunately 15 minutes late in leaving Windsor.

Ordinarily 100 people would have been on the station platform awaiting the Detroit train, but the day previous, August 9th, was a civic holiday with a very low excursion rate to Detroit, so that the crowd which usually going to Detroit Saturday morning went a day earlier.

The damage to property is outlined briefly below:

The freight station, 100 feet in length, about 220 feet from the explosion, had its western end totally wrecked. The roof was standing, but beginning 25 feet from the western end, it was cut through near the ridgepole as though by a knife, and the sides were thrown irregularly back and downward. The platform of the usual height was entirely undamaged. Several railroad ties were thrown on to this platform.

Piles of lumber back of the freight station were practically undisturbed. Farther to the east there were very few houses, and these were at a considerable distance. No damage was done except broken glass.

Several houses, 450 and 500 feet from the explosion, mostly of small value, were all more or less damaged, but none knocked down.

The Michigan Central passenger station, a two story stone structure with high gable roof and tower, about 18 years old, withstood the shock almost perfectly, though battered here and there by flying iron. The plastering and woodwork were entirely ruined. The nearest portion of the station was about 250 feet from the explosion.

A small section building, about 120 feet away, had the part toward the explosion blown entirely off, and the other half well shaken up.

A two-and-a-half story brick residence, costing probably \$4000 or \$5000, almost due north from the explosion at a distance of 275 feet, protected by a few scattered trees, was a complete wreck. One side had the bricks stripped off, and the roof was a confused mass of wood. Many boards and beams were dislodged within it, and pieces of railroad iron crashed through the walls. The wreck here was more complete than any other building, except some of the light wooden houses.

A lumber dry house, lightly constructed, 150 feet distant, had the roof caved in and the end facing the explosion entirely torn away. Many of the boards left on the sides were cracked and splintered from end to end.

A half dozen cross piles of about 6 inch logs nearer the scene of the explosion than the lumber dry house were entirely undisturbed.

At the lumber mill, the smaller building, 200 feet distant, had the end toward the explosion gone, roof torn up and sides burst out. The larger building, 250 feet distant, was crushed like an eggshell with the exception of the elevated portion in the rear, which was badly torn up, but not entirely knocked down.

A horse and wagon was standing within 60 feet of the explosion. The horse would doubtless have been killed by the shock in any case, but was speared by a piece of railroad iron, which went through him and into the ground. The driver was coming out of the lumber mill, about 150 feet away, and was struck in the face by wreckage, with serious damage to his beauty.

A building 300 feet away, where lumber was stored, was almost completely destroyed. Sides fell out and the roof fell in.

About 400 feet distant was a small frame house, worth perhaps \$1,200. At first sight no damage appeared except to doors and windows, but careful examination showed that practically every timber in the house was broken. Many boards running parallel with the force of the explosion were split and splintered throughout their length.

The same remarks apply to a house about 330 feet away, but the conditions here were even worse. From a distance the house appeared in fairly good condition, but a glance inside showed that it was crushed and broken and absolutely worthless.

A row of 4 small houses, distant 540, 560, 600 and 650 feet, were all more or less damaged, but none of them total wrecks. The plastering suffered severely, and all the windows in the house were blown out.

A house 380 feet distant, a barn 440 feet distant, and shed 380 feet distant, were all badly shaken up, sides bulged out and roofs crushed, windows, doors and plastering gone.

About 650 feet from the explosion was a frame house, injured in much the same way, except that it suffered less damage to the roof and sides, and can be repaired.

An elevator and planing mill, 350 feet distant, covered with corrugated iron, had its northeast corner very badly crushed. The slanting corrugated roof showed a bad dip, showing broken rafters underneath. The highest part of this building was probably taller than any in town, except the Methodist Church and the Town Hall.

A two story frame building 500 feet distant, perhaps costing \$2,000,

had its sides split from ground to roof at the corners, windows and doors gone, chimney standing but roof badly sagged. At the gable a hole about 4 feet on each side of the triangle had been blown in. This was a characteristic effect of the explosion on many other houses.

A newly built shed, nearly 700 feet from the explosion, had many boards split off and a characteristic gable hole nearly 10 feet on each side of the triangle.

In two houses, 500 and 720 feet away, certain rooms showed the paper split from the ceiling but undisturbed on the sides of the rooms, while other rooms showed the side walls stripped, but the ceiling nearly intact.

A two story residence, 750 feet away, was practically undisturbed save for glass, one door, and some plastering.

A dwelling 575 feet distant, and fairly well protected by high buildings all around, lost only its chimney, windows and front door.

The buildings on a block of Main Street, distant about 950 feet, were badly shaken up, many boards ripped off, nearly all chimneys gone, glass out on all sides; but none of them beyond repair.

The Methodist Church, about 850 feet from the explosion, was a brick structure with a steeple. The outside walls were practically uninjured, but every pane of glass was shattered, all plastering stripped from walls and ceiling, and a bulge in the roof about half way between the eaves and ridge-pole indicated that the roof's back was broken, as happened in many other cases. One corner of the building to the northeast was separated from the main body of the church by glass doors. These doors were torn from their hinges and smashed, with the exception of one which was in its place with every pane of glass unbroken.

At the Town Hall, to the southwest of the Methodist Church on the main street, about 1250 feet away from the explosion, the damage was comparatively light, unless two cracks in the northern and eastern walls proved serious.

A dwelling house, about 600 feet north of the explosion, was damaged in the usual way, but the glass blew outward and curtains were torn from their hangings and were sucked outwards into trees in the yard.

The next house to this, a residence of one of the leading citizens of the town, distant about 500 feet, showed the same suction. Even the foundation walls of brick were pulled outward in seven or eight different places, the bricks coming in some cases ten or fifteen feet into the yard. This house is practically ruined inside.

The brick residence, about 400 feet distant, was ruined. Condition of the interior was what would naturally be expected. One of the gables had the triangular section blown neatly out. The shed in the rear was knocked to pieces.

A frame structure worth about \$2500, distant 350 feet, was an absolute wreck, crushed and useless.

An old box car, used as a shed, had the corner nearest the explosion knocked out. The balance was standing, but every board on the east side was torn across the grain, while the boards of the roof were splintered along the grain.

A grist and saw mill, distant 300 feet, was crushed to the ground except where supported by the lumber piled within.

A large three story frame house, 720 feet distant, used as a tavern, was hopelessly wrecked; the roof was badly wrecked, and on it was a big timber, probably 18 feet long by $1\frac{1}{2}$ feet wide, and 6 inches or more thick, probably blown from one of the lumber piles or from the roof of the station, more likely the latter.

A carriage factory, two stories high, of frame construction, distant 570 feet, had in the east wall a hole 30 or 40 feet long and 8 or 10 feet wide. The building was a wreck.

Houses on both sides of main street, about 900 feet away, were damaged in the ordinary manner, that is, lost windows, more or less plastering, chimneys, etc. One showed the peculiar triangular cut out under the gable.

A row of buildings extending for about two blocks on the main street of the town, distant 950 feet to 1100 feet, included the large stores, banks, restaurants and office buildings, many of which were constructed of brick. These lost their windows and much plastering. Some of the stores received heavy damage to their stock, particularly those handling fragile ornaments and silver. The latter was dented in many cases. The stores and houses along this street did not show the damage very much, except as to the windows, but the actual money loss to the owners was very heavy.

Roughly speaking the property loss could be said to be almost absolute up to about 300 feet. Between 300 and 500 feet, the damage was severe, and in some cases entire. Between 500 and 1000 feet it varied from almost entire to trifling. Some glass was broken from 10 to 20 miles away and a farmer claimed to have been knocked down in a field nearly a mile and a half away from the scene of the explosion.

Essex was situated on an almost level stretch of ground, the only higher land being in the residence quarter to the southwest, where damage was confined to broken glass, ornaments and plastering. This section was 1050 to 2500 feet from the point of the explosion. The balance of the village was unprotected except by trees. There were a considerable number of large elms, with some other shade trees along the streets, more of them toward the north than in any other direction. Apparently they were too scattered to give much protection. The trees did not suffer at all. Large elm trees

on the street to the east of the station were entirely unaffected, no branches being torn off or other injury apparent.

The evenness of the ground and the fact that there was no air stirring at the time account in all probability for the evenness with which the explosive force was distributed. While most of the damage was done to the southeast and northeast, this was merely because more property happened to lie within the radius of destruction in these directions. The few buildings situated to the northeast and south suffered very severely, and it appeared that the air currents went in each direction with approximately the same force.

Newspaper accounts stated that a quantity of nitroglycerin contained in the car caused the widespread destruction. The belief is based on two facts, first the leakage from the car to the track, and secondly the feeling that ordinary dynamite would not have done the damage which resulted from the explosion. This belief was held by the town council, and by some of the railroad employees, as well as by the town people generally. There can be no question that the theory was wrong. It was against the Canadian law to ship nitroglycerin by rail. The shipment in question was billed as powder cartridges, so that shipment of nitroglycerin would have been under false designation, which would be a serious offense. Parties who entered the car were accustomed to see dynamite in the boxes they saw there, and if nitroglycerin had been present the difference in packages would have been noted. Moreover, the shipment had been inspected and passed the customs.

In filling up the right of way after the explosion, the yard men heaped up a large pile of debris consisting of scraps of iron, charred pieces of wood, battered tin cans and similar material, and in the pile was found a small piece of unexploded dynamite. Further investigation showed that more or less dynamite was scattered through this heap. From surface indications, there was probably 50 or 100 pounds in the entire pile. It was all in small pieces, and not much of its condition could be obtained from the pieces which were picked up. It showed, however, absolutely that the explosion was of dynamite. No unexploded dynamite was found in the fields or yards in the neighborhood, and from all appearances practically the entire shipment exploded.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Church	None	Roof broken and plaster knocked down	800
Area of structural damage.....			800 feet
Charted.....			400 feet
Glass broken, up to.....			10 to 20 miles
Missiles thrown, up to.....			500 feet

CABOT, PENNSYLVANIA

Chart No. 119

On July 14, 1910, at 6:45 A. M., there was an explosion in the powder magazine at a quarrying operation located about one-half mile west of Cabot, Pennsylvania.

The magazine consisted of one inch oak boards of various widths for siding, with a 2" plank floor and a flat roof covered with tar paper. It was about 10 x 20 feet and stood in the clearing about 40 feet square, well located and effectively screened by brush and timber around it, growing so densely that it was impossible to gain entrance to the magazine except by the path that led from the quarry.

In the magazine near the door were stored about 1000 lbs. of dynamite, and in the far end there were two hundred kegs, containing 5000 lbs. of black powder, lying on their sides. This made a total of 6000 lbs. of explosives. To the right of the door there was a shelf on which were stored caps and fuse which, in view of the fact that the magazine contained high explosives, was a poor practice.

The assistant shooter of the quarry had gone to the magazine to get some dynamite, caps and fuse, and had been in the building but a minute or two when the explosion occurred, instantly killing him. The cause of the accident was unknown. Although the assistant shooter was a smoker, he had the reputation of being exceptionally careful and he had held his position for six years.

The explosion formed a crater about 20 x 30 feet, 3 feet deep at the end where the powder was stored, and 3½ feet at the point where the dynamite was stored. There was only one explosion.

The nearest building to the magazine site was a frame dwelling 200 feet distant, directly in front of the magazine, but on a level 20 feet below the magazine site. The porch on the front of the house was blown off and the side of the house towards the magazine was blown in. Four children and a woman, who were in a room in the house, were uninjured. A shed near the house was not damaged.

About 350 feet away was the main plant of the quarry. This frame building had quite a number of rafters broken, part of the sheet iron roofing blown off, and the side of the building towards the explosion blown in. Attached to this main building were two belt rooms, one of which had the roof lifted and the sides blown in, while the other was undamaged.

Beyond the main building was a barn and three frame dwellings, distant between 400 and 600 feet from the magazine. The barn was moved about an inch from its foundation and the dwelling had a few panes of glass broken. A stone from the foundation of the magazine was thrown through the roof of one of the houses.

The town of Cabot, about half a mile away and protected by well-wooded hills, felt the concussion but suffered only the loss of a few panes of glass.

Quite a number of trees within 100 ft. radius of the explosion were stripped of their foliage, but there was no indication of a fire, although the people in Cabot claimed that burning leaves, together with dirt, came down on house roofs and porches for about five or ten minutes after the explosion.

The assistant shooter was the only one killed. The assistant engineer in the main quarry building had his hand slightly cut endeavoring to catch a falling window sash. Eight or ten men working in the quarry, which was about 500 feet away with a 25 ft. hill intervening, were not injured in any way.

Missiles were thrown 500 feet and glass was broken in Cabot, about half a mile away, well protected by wooded hills.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Belt house	Woods and dense brush	Roof blown off, side blown in	350
Area of structural damage.....			350 feet
Charted.....			350 feet
Missiles thrown, up to.....			500 feet
Glass broken, up to.....			2640 feet

MARQUETTE, MICHIGAN

Chart No. 68

On December 16th, 1905, at 8:45 A. M., there was an explosion in the dynamite mixing house of the explosives plant at Marquette, Michigan. The building was of light frame construction, built with 2 x 4 studs and 2 x 6 rafters. There were no artificial barricades, but the grove of pine trees afforded some natural protection.

The mixing house contained one set of mixing wheels. The method of working was to bring the washed nitroglycerin, a charge at a time, in a traveling tank from the separating house, draw the same into a storage tank, and from this into rubber buckets which were poured into the tub. Because there was no other storage for nitroglycerin, it was always necessary to carry overnight considerable quantities of nitroglycerin or powder to supply the powder houses in the morning. There were no arrangements for sifting dope.

At the time of the explosion there were four men in the house and one

man just outside. Two of these were truckers, and the other three belonged to the regular crew of the house. These men were killed instantly. Five other men were slightly injured.

The foreman was out of the house at the time, having gone to the general foreman for instructions. From his statement, it was known that the mixing tub had been stopped, and nitroglycerin for the next charge weighed out before he left the house, and as he himself always attended to the starting and stopping of the mixer, the explosion could not have been connected with the motion of the mixing wheels. The truckers had just come to the house, and one of the packing machines had signalled for powder. From the fact that there was a decided depression in the ground where the truck stood, it is evident that part, at least, of a mixing had been carried out to the truck. The mixing house men had been unable, before the arrival of the truck runners, to shovel the mixing out of the tub, for the reason that until these men brought empty boxes, they had no boxes in which to put the powder. Therefore it is probable that the men were at the time shovelling powder out of the tub, and possibly also handling powder out onto the truck.

At the time of the explosion, a charge was being nitrated in the nitroglycerin house, nearly all glycerin having been run in. The building was so badly damaged by the force of the explosion that the engine driving the nitrator stirrers was rendered useless, and by the fall of the roof, the gearing of the nitrator was blocked and the air pipe broken, making it impossible to continue stirring the charge. A piece of one of the rafters of the building fell through the glass window in the top of the nitrator, and by the time the men removed this, fumes were beginning to come off the charge, and the men left the building. The charge burned up entirely without exploding and without setting fire to the building. It was noticed that there had been a slight explosion in the air pipe at the bottom of the nitrator, and in the bottom of the nitrator, which was of sheet steel, there was a crack about 28 inches long near the air pipe. From the appearance of this crack, it seemed more as if it were due to a flaw in the iron, than to the force of the explosion.

At the time of the explosion there was in the house 1650 pounds of 50% dynamite, 550 pounds of which was in the mixing tub, 1800 pounds of 35% ammonia dynamite, and about 2630 pounds of nitroglycerin, making a total of 6080 pounds of explosives.

The cause of the explosion was not known. The weather was mild, and there was no possibility of frozen powder.

The mixing house was totally destroyed, and where the building stood there was a depression in the ground 14 feet in diameter and 30 inches deep. Very little of the building was found in large pieces, as it was splintered. Parts of the engine were blown into the Dead River, and truck wheels were

blown over the plant. Engine parts, such as cylinder, flywheel, crank shaft, connecting rod and vertical shaft, were thrown in a northerly direction. Within a radius of 100 feet, trees were broken off, blown to the ground or leaning at various angles. Those in line with the dope house were scorched on the mixing house side. Tramway track and trestles were destroyed 100 feet each side of the building. From 150 to 400 feet radius, the ground was strewn with tree branches and twigs.

Structural damage to the plant was as follows:

The dope house, 100 feet from the explosion, was crushed, only one side remaining standing. The only parts not affected were the foundation, joist and flooring. The force of the explosion crushed and broke the sides and roof and made a wreck of the house.

The nitroglycerin house, 200 feet distant, had its side, roof and end crushed in; the building was so badly wrecked that it had to be rebuilt.

The glycerin heater house, 200 feet away, had the side toward the mixing house pulled out, the end toward the nitroglycerin house and half the roof toward the mixing house blown in; doors and windows forced in. There was a hole in the side toward the mixing house as though a bolt had been driven through it.

The valve house had the end toward the mixing house blown in, doors wrecked and glass smashed.

The mixed acid weighing house, 300 feet away, had corrugated iron torn off, rafters and collar beams badly broken, and the air pipe broken off.

The ice house, 325 feet away, had the side and the end pulled out, and the roof broken and forced in. The building was practically wrecked.

The separating house, 550 feet away, had all glass broken. The glass on the mixing house side was hurled across the building and driven in the wall on the opposite side. The door on the mixing house side was torn off and driven in.

The punching house No. 1, 450 feet distant, had one side and half roof the facing the mixing house blown in. One gable end was forced out, and the door and window sash wrecked.

The punching house No. 2, 275 feet distant, had its roof smashed, and the end of the building towards the mixing house stove in, and sides badly sprung; all doors and windows wrecked.

The punching house No. 3, 725 feet away, had doors and glass broken.

The punching house No. 4, 525 feet away, had the end, side, and half the roof toward the mixing house crushed in; doors and windows wrecked.

The box packing house, 425 feet away, had the gable end toward the mixing house crushed in; doors and windows wrecked. The roof of the annex was blown in, and the side of building toward the mixing house pulled out at the bottom.

The box store house, 575 feet away, had galvanized iron torn off, studding, rafters and collar beams broken.

The powder office, 550 feet away, had windows and doors blown in, and the ceiling loosened on one side.

The soda store house, 575 feet away, had its corrugated iron roof torn off and a few rafters broken.

The soda dry house, 575 feet away, had the corrugated iron roof torn off, and windows broken in.

The power house, 750 feet away, had windows, a few rafters, studding and collar beams broken. Corrugated iron was twisted in some places. The gable end was forced in at the top. On the brick walls, where the cornice and eaves meet, the masonry was somewhat broken away from the rafters.

Glass was broken to a distance of about a mile and a half.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Power house	Trees considered as affording some protection	Rafters, studding and collar beams broken, brick walls broken from rafters	750
Area of structural damage.....			750 feet
Charted.....			750 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			1½ miles

PINOLE, CALIFORNIA

Chart No. 56

There was an explosion at the explosives works at Pinole, California, on September 5th, 1907, at 1:25 P. M. It occurred in the gelatin machine cartridging house No. 1. This building was barricaded.

About 6350 pounds of gelatin powder was estimated to have been involved in the explosion. There was in front of the building at the time a car containing about 125 cases of gelatin powder, which had been packed in the morning, and which would have been moved, in the ordinary course of events, in an hour. In addition to this, there was in the building 500 pounds of loose gelatin, which had just been delivered from the gelatin mixing machine, and 5 cases of odds and ends of powder packed the day before.

Conditions in the house just previous to the explosion are reported to have been all right. The machine was operating smoothly, and there was

nothing to indicate what caused the trouble. The crew of the house, consisting of two white men and two Chinamen, were killed. No one was injured.

The gelatin machine packing houses Nos. 2 and 3 were more or less damaged, and the shafting was out of line in No. 2. The wheel mixers in the dynamite mixing house were also out of line. The damage to other buildings was nominal. Slight structural damage all occurred within a radius of 625 feet.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Powder buildings	Barricaded	Shafting out of line	625
Area of structural damage			625 feet
Charted			625 feet
Missiles thrown, up to			No record
Glass broken, up to			No record

EMPORIUM, PENNSYLVANIA

Chart No. 62

There was an explosion at the Keystone Powder Plant at Emporium, Pa., on November 27th, 1905, at 12:10 noon. The explosion occurred in the mixing and packing houses, which went off simultaneously.

The powder line consisted of a mixing house, containing two hand mixing tubs, as well as a storage tank for nitroglycerin; three packing houses, the first of which was between 60 and 80 feet from the mixing house, and the others spaced 50 to 60 feet apart down the valley. Two shell store houses were located in the spaces between the packing houses. All these buildings were protected by substantial earth barricades, 10 by 12 feet wide and of the same height.

Lower down the valley, 500 to 600 feet distant from the mixing house, were located the box packing house and box house.

Up the valley, 250 to 500 feet from the mixing house, was the Safety Area of the plant, soda dry house, Big Chief dope house, power house and laboratory.

Above this again was the nitroglycerin plant.

In the mixing house at the time of the explosion there was a mixing in each tub, probably amounting to 500 pounds each, 2000 pounds of nitroglycerin in the storage tank, and in the ground under the house probably 3000 pounds of nitroglycerin which, owing to a broken rubber hose, had been spilt during the summer; making a total of 6000 pounds.

In the No. 1 packing house there was 500 pounds of powder. This made the total amount of explosive in both houses 6500 pounds.

The four men in the mixing house, one man passing the mixing house, and four men in the No. 1 packing house were instantly killed. The seven men in the other two packing houses escaped without serious injury, except for one man whose leg was broken.

There was no suggestion of a probable cause. From the fact that the mixing house contained the larger amount of explosive, and that No. 1 packing house was nearer No. 2 packing house than to the mixing house, it is probable that the mixing house must have exploded first.

It is of interest to note that there was a small explosion a few minutes after the first, due to a stream of water thrown on burning Big Chief dope.

The mixing house and the packing house were completely destroyed. The remaining packing houses and small shell store houses were more or less completely demolished, the ones nearest the mixing house being pretty well flattened down.

Box packing house and box store house, 500 to 600 feet distant, had their roofs stove in, and the nearer one had the end stove in.

The roofs of the soda dry house, Big Chief dope house, power house, laboratory, and other houses in the safety group were demolished, but the stone walls were still standing. In the case of the soda dry house, the heavy stone walls were displaced 6 inches to a foot, and the steel and sheet iron roof fell down on the man within, injuring him somewhat.

The gelatin building was completely demolished, but the gun cotton dry house just back of it was not severely damaged. The nitric acid houses had the ends and part of the roof stove in, and most of the chemicalware broken. The acid recovery house and the nitroglycerin house on the upper end of the works, as well as the storehouse on the lower end of the works, were practically undisturbed.

The crest of a hill intervened between the plant and the town of Emporium, about a mile away. The damage in the town consisted only of broken glass.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Box packing and box store house	Barricaded	Roofs and end stove in.	600
Soda dry house		Roof smashed and stone walls displaced.	500
Area of structural damage.....			600 feet
Charted.....			600 feet
Glass broken, up to.....			1 mile
Missiles thrown, up to.....			No record

HAZARDVILLE, CONNECTICUT

Chart No. 172

An explosion occurred on a powder plant at Hazardville, Connecticut, on January 14th, 1913, at 1:30 P. M.

The press mill in which the explosion occurred contained 6700 pounds of sporting powder. Investigations showed that one complete pressing had been passed through the cut rolls into a hopper car. The press box had been filled and probably run out on first butting, and the ram let back to receive the second filling. It would appear that the men were in the act of putting powder in the press box for the final filling when the accident happened, and that no machinery was then running.

The two employees in the building were both old and experienced powdermen. They were instantly killed, and another employee who was driving a transportation wagon within 250 feet of the explosion, was thrown to the ground and severely bruised and shocked. Several men in nearby buildings received slight bruises and cuts, but no serious injuries.

The force of the explosion was severe, and was communicated to wheel mills Nos. 2, 3, and 7, respectively 325, 475 and 590 feet distant from the press mill. It was estimated that at the time of the explosion there was altogether in these mills about 2,000 pounds of powder, which exploded. Burning brands fell on the roofs of these buildings and ignited powder dust which had been shaken out by the concussion.

Damage to the village property covered a distance of over a mile to the east, and three-quarters of a mile to the north and northwest. The damage was almost entirely confined to breakage of glass, sash, and plaster. Serious damage was done to stained glass windows in three churches. Press plates were thrown to a distance of 800 feet, mostly in a northerly direction.

An interesting feature of this explosion was the test given to pole barricades, then a new type of protection. A barricade built of chestnut poles, 20 feet high and planted 4 or 5 feet in the ground, had been erected on the west side of the press mill. After the explosion, only six poles of the entire barricade, which was about 50 feet long, remained standing and those were badly bent out of position. The rest of the poles were torn violently out of the ground, many of them shattered to long splinters and thrown to distances as great as 350 feet. Others were broken into five or six foot lengths and hurled as far away as 750 feet. Two of the poles were thrown high into the air and when they struck the earth 150 feet away, they penetrated five or six feet into the ground in an almost vertical position. Owing to their weight and size they made dangerous missiles, capable of doing much destruction to nearby buildings, and constituting a serious menace to persons within a radius of 700 to 800 feet.

Very little structural damage was done beyond a radius of 700 feet. This damage consisted of broken rafters, and the removal of portions of the side coverings of the cooper shop, cooper shop storehouse, glaze, charge house, engine room, boiler room and coal shed.

The force of the explosion was felt in two distinct directions, northwest and northeast, the ground being covered with debris for 250 feet. To the southwest and towards the corning mill, very few missiles were found, practically none beyond 200 feet. Missiles were thrown 800 feet to the northeast. Glass was broken at distances of over a mile.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Wooden buildings on plant	Pole barricade	Broken rafters	700
Area of structural damage.....			700 feet
Charted.....			700 feet
Missiles thrown, up to.....			800 feet
Glass broken, up to.....			Over a mile

WILMINGTON, DELAWARE

Chart No. 18

An explosion occurred at the Brandywine Powder Works near Wilmington, Delaware, on March 8th, 1909, at 6:50 A. M.

The first explosion was in the experimental glaze barrel at Hagley Yard, followed almost immediately by the second explosion in the corning mill, 180 feet away.

The glaze mill was protected by a stone and earth barricade. At the time of the explosion there were about 80 kegs of finished fuse powder in the mill, amounting to 6,700 pounds. The cause of the explosion was unknown.

The power house, electric light plant, power house No. 2, and some large buildings in the lower yard, including the keg shop, band room and construction shop, all were severely shaken up, sash blown in, and glass broken. Damage to glass extended to the western part of Wilmington, but structural damage did not extend beyond 300 feet.

One man was killed in this explosion, and one man was slightly injured on the street car nearby.

Missiles were thrown 900 feet, and glass was broken at a distance of half a mile.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Plant buildings	Stone and earth barricade	Severe shocking	300
Area of structural damage.....			300 feet
Charted.....			300 feet
Missiles thrown, up to.....			900 feet
Glass broken, up to.....			½ mile

VIGORIT, CALIFORNIA

Chart No. 97

There was an explosion at the Vigorit Explosives Plant at Vigorit, Cal., on January 10th, 1907, at 10 o'clock, in the nitroglycerin separating and wash house. The barricades around the building were of good height and quite heavy.

About 7000 pounds of nitroglycerin were in the building at the time of the explosion.

The foreman of the nitroglycerin line was in the building about 20 minutes before the explosion, and he reported everything in first class condition. The foreman of the dynamite mixing house, who had been there only five minutes before, reported everything normal. The last charges of the day were being drowned, the separation of the nitroglycerin having been in progress for 20 minutes or more. The cause of the explosion could not be surmised.

One man, the employee in the house, was killed. No one else was injured.

Structural damage to the plant was limited to 300 feet.

The oil storage house, 200 feet away, was moved off its foundations about an inch and a half, and windows shattered.

The dynamite mixing house windows were broken, and one of the mixers thrown badly out of line.

The Hall dynamite cartridging machine house had shattered windows, and the whole roof lifted three inches; and the machine badly damaged.

The old mixing house, which was being used as a Quinan packing machine house, was the worst wreck on the plant. The entire roof was thrown in, and the condition of the house was such that it had to be torn down.

The nitroglycerin nitrating house sustained severe injury. The old walls had to be torn down, and many supports, braces and parts of the roof had to be replaced.

Glass was broken to a distance of four miles.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Mixing and packing house	Barricaded	Badly damaged	300
Nitroglycerin nitrating house		Side broken in	200
Area of structural damage			300 feet
Charted			300 feet
Missiles thrown, up to			No record
Glass broken, up to			4 miles

FAVERSHAM, ENGLAND

Chart No. 125

There was an explosion of the Marsh Powder Works, Faversham, England, at 9:40 A. M., on February 21st, 1879. The glazing house, in which the explosion occurred, was a low, one-storied wooden building about 61 feet long by 25 feet wide, (exclusive of boat shed) standing on a brick foundation. It was provided with a double roof, the roof having originally consisted of a tank to contain water for fire protection; but the tank leaked, and had ceased to be used for that purpose, and an outer slated roof had been constructed over it. This heavy roof construction no doubt largely contributed to render the effects of the explosion widely destructive.

On the northeast side of the glazing house ran the water course, covered in front of the building by a boat shed, under which the powder for conveyance to and from the house was loaded and unloaded.

* Inside there were ten pairs of glazing tubs, each tub 5 feet 2½ inches long, and 2 feet 2 inches in diameter at the bilge. Tubs were constructed of wood 1½ to 2 inches thick. They were set 12 inches apart, and the total length of the wooden shaft which supported each pair was about 13 feet long. Each pair of tubs would hold about 720 pounds of powder, giving a total glazing power for the house of 7020 pounds. The tubs were generally driven at a speed of 28 revolutions a minute.

The explosion occurred about 9:40 A. M., five minutes after a boatman had left the house with a boatload of powder, and when no person except the glaze operator was in the immediate vicinity of the house. The fact that his body was blown to atoms testifies that he was on the spot at the time of the explosion. Eight men were injured.

Examination into the cause of the explosion failed to bring out anything of a definite nature, the theory being advanced that it was due to breakage of equipment.

The glazing house was not mounded or screened in any way. It was separated from the engine house, from which it derived its power, and adjoining brick watch house by the enormous traverse of each, and a high substantial brick wall. The ground was level and there was no impediment to the free lateral distribution of the effects of the explosion except for the traverse mounds mentioned, and a thick surrounding plantation of small trees.

The building itself was completely destroyed by the explosion. Portions of the timber, charred and broken, were projected for several hundred yards in the direction the wind was blowing, and over 100 yards in the opposite direction. The machinery was broken up into fragments, and pieces were projected to 367 and 467 yards respectively in two instances.

A careful examination of the effects of the explosion establish the areas affected approximately as follows:

Figures may be taken as feet.

Radius of scorching effects, or flash.....	120	150
Serious structural damage, brick buildings.....	396	600
“ “ “ wooden “	850	900
Broken window frames, sashes, ceilings, doors,		
On flat.....	1100	1200
On high ground.....	2700	3000
Dangerous projection of debris.....	1400	1500
Broken glass, 50 panes.....	About 1 mile	

The stove, 396 feet away, was the farthest brick building which sustained serious structural damage, except the carpenter shop, 700 feet distant; but damage to this second building could be regarded as exceptional, since other brick buildings considerably within the distance, unprotected except by trees, sustained no structural damage. The damage to the carpenter shop was largely due to the light construction of the building, or deflected explosion waves.

The saltpetre refinery, about 900 feet away, was the farthest wooden building which sustained what might fairly be called structural damage, except the exceptionally lightly-constructed incorporating mills at 1560 feet.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Saltpetre refinery	No barricade	Roof damaged, sides sucked in partially	900
Area of structural damage.....			900 feet
Charted.....			450 feet
Missiles thrown, up to.....			1500 feet
Glass broken, up to.....			1 mile

BARKSDALE, WISCONSIN

Chart No. 9

There was a severe explosion on the high explosives works at Barksdale, Wisconsin, on September 15th, 1908, at 9:55 A. M.

The explosion occurred in the No. 2 nitroglycerin neutralizing house, which was of wood construction, and barricaded with double-faced, or crib earth-filled barricades.

There were three charges of nitroglycerin in the building at the time of the explosion, two of which were neutralized and a third just received from the separating house. It is quite probable that most of this charge had been received in the neutralizing house, since the explosion only extended up the gutter some 400 feet of the 720 feet of gutter between the separating and neutralizing houses.

The superintendent of the works left the neutralizing house to go to the separating house about three minutes before the explosion, and had reached a point on the walkway alongside the nitroglycerin gutter slightly beyond where the destruction of the gutter ended. His injuries consisted of lacerations and contusions, a ruptured eardrum and a sprained ankle.

The neutralizing house had been visited about 15 minutes before the explosion by the assistant superintendent and everything was found to be in good condition.

The neutralizing house was entirely demolished, and the operator instantly killed.

The cause of the accident was unknown, and no theory was advanced to explain it.

The following buildings suffered structural damage:

The nitroglycerin storehouse No. 1, protected by artificial barricades, had framing and rafters broken. It was 700 feet away.

The power house and O. V. plant, partially protected by the configuration of the ground, suffered minor damage to brickwork.

There were a few scattered missiles located up to 1000 feet, and one weighing two pounds was found at 1500 feet from the explosion.

The glass breakage in the works was fairly general, and a few plate glass windows were broken in the towns of Ashland and Washburn, six miles away. Two windows were broken 15 miles away, at Bayfield.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Nitroglycerin storehouse No. 1	Barricaded	Framing damaged	700
Area of structural damage			700 feet
Charted			700 feet
Missiles thrown, up to			1500 feet
Glass broken, up to			15 miles

HOUNSLOW, ENGLAND

Chart No. 131

An explosion occurred about 8:56 A. M. on the 3rd of May, 1887, at the Hounslow Factory, near Hounslow, England, in the lower glazing house, in which there was 7500 pounds of powder.

The lower glazing house stood on the south bank of a straight canal. It consisted of two unequal compartments about 10 feet high, one on either side of a waterwheel by which the machinery was driven. In the west compartment, which was 35 feet long by 20 feet wide, there were 8 glazing barrels, arranged in sets of four wheels each (four barrels secured together outside a shaft, and revolving around it) and in the east compartment, which was 26 feet long by 20 feet wide, in which there were four glazing barrels in two ranges, a shaft passing through the center of each.

The building was lightly constructed of feather boarding on brick foundations, with tiled roof and the compartments were lined throughout with match-boarding. The floor was of wood partly covered with hides. There was a platform in front of the building.

The ground on the northeast and west sides of the building was covered with lofty sycamores, horsechestnuts and poplars, supplemented by a thick undergrowth of willow and alder, all of which served to minimize the results of the explosion as regards structural damage to a very limited area. Had the trees been fully leaved, they would have afforded greater protection. On the south side there was a little undergrowth only, but there were no factory buildings in that direction.

Only one man, the glazing house operator, was in the building at the time of the explosion. His body was blown to fragments, pieces being picked

up at distances from 150 to 900 feet. No injuries were sustained by any of the workpeople of the factory, or by anyone outside the factory. The workmen nearest the building at the time were three men employed in the lower corning house, the machinery in which was running. The corning house was about 345 feet from the glazing house, screened by a high substantial mound, and by trees and undergrowth. The concussion of the explosion caused it to be filled with dust from the powder under manipulation, and from the walls and roof, rendering it so dark inside that the men were forced to grope their way out of it.

No cause for the explosion could be given.

The greatest force of the explosion was expended towards the north, in which direction the range of flash was about 105 feet, and towards the east, where the range of flash was about 60 feet. The undergrowth was nearly all cut off close to the ground up to these distances, and 12 large trees were broken off at various heights up to about 20 feet. Towards the west, the effect was much less marked, and still less towards the south.

The heaviest pieces of machinery were hurled towards the southwest, two pieces of shafting were found 600 feet off, and other parts of the machinery up to about 930 feet.

The wind was light at the time and blowing from the southwest, and as the glazing house was sheltered by the trees, it had little effect upon the results of the explosion.

At the time of the explosion, the "ranges" and "bunches" (glaze barrels) contained 3800 pounds of gunpowder in process of glazing, and there was a further quantity of 1900 pounds of glazed and 1900 pounds of unglazed gunpowder in tubs, the greater part of which was on the platform for removal.

The walls and roof of the compartments were blown to pieces, but the floor was little damaged. It was raised with the rafters which supported it and carried about five feet. The portion of the platform in front of the compartment was also very little damaged, and was not displaced.

The effect of the explosion upon the other buildings of the factory was slight. Excepting the lower stove, distant about 130 feet, one wall of which was bulged outwards and cracked, and the boiler house, distant 180 feet, one wall of which was partly blown down, and two other walls cracked, there was no structural damage of any importance. The buildings damaged were built of brick, with tile roofing, the supporting timbers of which were cracked and broken.

The stove and boiler house were screened, except one corner, by a good mound and trees. There was about 50 pounds of gunpowder in the stove at the time. A wooden boat house adjoining the stove was destroyed by the explosion.

The lower corning house, distant 345 feet, was struck by a piece of machinery, which made a hole in the planking about 5 feet long by 2 feet high, and broke two uprights supporting the building. The hole was about 3½ feet above the level of the platform.

The injury to other buildings inside and outside of the factory was of a quite insignificant character, and consisted for the most part of broken panes of glass only. The ceilings of some cottages were cracked. Glass was broken in Hounslow, 2 miles away, and in surrounding towns.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Boiler house	No. Other houses protected, screened by trees	Wall blown down	180
Area of structural damage.....			180 feet
Charted.....			90 feet
Missiles thrown, up to.....			930 feet
Glass broken, up to.....			Several miles

SCHAGHTICOKE, NEW YORK

Chart No. 87

An explosion occurred at Schaghticokè Powder Mills, Schaghticoke, New York, on May 10th, 1904, at 9:30 A. M. in the corning mill, involving the press mill 120 feet away, which exploded a few seconds later, ignited by flying fragments. These buildings had wood and earth barricades. There were 2000 pounds of explosives in the corning mill and 5800 pounds in the press mill, so that a total of 7800 pounds of explosive was involved.

A few minutes before the explosion the two press mill men passed the corning mill, going to the separating house to obtain material for the press. At that time the corning mill was running, cutting down the fine grain from FFFg into fuse powder. Eighteen barrels of grain had been corned down, and three barrels remained to be cut down. There was also a half press cake ready to be corned as soon as the fuse powder had been run. The press men stated that the mill was apparently running in good order, and no word had been heard by the foreman that anything was wrong.

No explanation could be offered for the explosion. As the mill had been blown into the river, the debris could not be examined, so that nothing could be learned as to the cause.

The explosion was very sharp, and caused considerable damage in the

vicinity. The man in the corning mill was killed instantly by the explosion, and the assistant foreman was killed instantly by a fragment of the press, which struck him as he was passing the mill.

The corning mill was a complete loss. The press mill was demolished, except for the ram, which was apparently uninjured.

The worst damage to the buildings near the explosion was done to the glazing mill, charcoal house, and to the office. The slate-covered roof of the charcoal house was so much injured that it had to be rebuilt. The walls, however, were not hurt. The glaze mill, a frame building, had only a few boards torn off and the framework shaken. The side wall of the office was bulged in by the concussion.

450 feet was the limit of structural damage. Missiles were thrown 300 feet, and glass was broken one-half mile away.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Frame building	Wood barricade	Wall bulged, roof damaged	450
Area of structural damage.....			450 feet
Charted.....			450 feet
Missiles thrown, up to.....			300 feet
Glass broken, up to.....			½ mile

MT. CARMEL, PENNSYLVANIA

Chart No. 71

An explosion occurred in a magazine at the Richards colliery near Mt. Carmel, Pennsylvania, on March 5th, 1907, at 8:15 A. M.

The magazine was built of one-inch hemlock boards, set vertical and battened, and was lined with yellow pine matched boards, with a corrugated iron roof. It was about 16 x 20 feet in size, and was situated on the hillside, about 45 feet south of the team road. It was not barricaded. There was a ridge between the magazine and the town of Mt. Carmel.

The explosion occurred just one hour after the morning supply of explosives had been issued, and the magazine locked up. No one was known to have returned to the magazine in this time.

8000 pounds of explosives was stored in the magazine at the time; 1500 pounds of 60% gelatin, 4000 pounds of Enterprise coal powder, and 2500 pounds of black powder.

No one was able to offer any explanation of the cause. Workmen had been passing to and fro in the near vicinity of the magazine just before the

explosion, and they would have noticed if the magazine had caught on fire from the outside.

The magazine was heated with live steam, but the pipe leading to the radiator was about 700 feet long, and the radiators heating the carpenter and machine shops, office, oil house and supply house, were all connected first, the magazine radiator being on the end of the line. It is not probable that the temperature of the magazine was dangerously high so soon, since the door had been standing open for some time, while the explosives were being given out.

The explosives were issued by a boy, who doubtless carried matches in his pockets, and fire might have started from matches dropped on the floor; or possibly the boy might have placed a box of caps too near the radiator. All explosives as a rule were stacked at a safe distance from the radiator. It was the custom to permit no one but colliery or supply clerks to enter the magazine, all explosives being handed out over the lower half of the door.

The workmen stated that there were a great many rats about the magazine, and it was suggested that they might have been responsible in some way for the accident.

Although there were some 20 people within 450 feet of the magazine, only one man was killed and one boy seriously injured. The man who was killed was a Pole, who at the time of the explosion was sitting in a small shanty in the lumber yard east of the breaker, and 1125 feet northeast of the magazine. When he heard the report, he rushed out of the shanty, and was almost immediately struck in the head by a piece of stone weighing a couple of pounds, apparently a stone from the magazine foundation, which fractured his skull. A breaker boy who was in the machine shop had both legs broken when the roof structure, to which were attached the pulleys and counter shafts, fell in. A few other men were slightly cut by glass.

A crater was left on the site of the magazine 40 feet in diameter and 8 to 10 feet deep.

The explosion destroyed completely the small fire house, the supply house, the oil house and the office. The machine shop was so damaged that it had to be taken down. The engine houses and cement house were considerably battered, but were easily repaired. The locomotive house, lamp house, fire pump house, fan house, and two dwelling houses showed little damage besides broken window sash and glass. The stable, scraper engine house, shipper's office and locomotive house showed practically no damage, only a few of the windows being broken. The boiler house and breaker house were damaged to a greater extent. The breaker house had a number of plates of corrugated iron siding torn off. It was difficult to estimate just how much of the damage to the boiler house was due to the explosion, as

it was a very old structure. About 600 feet was the limit of structural damage.

Missiles were thrown 1125 feet. Glass was broken to a considerable extent in the town of Mt. Carmel, over the ridge and $\frac{3}{4}$ of a mile distant.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Engine house	No barricade	Considerably damaged	600
Area of structural damage.....			600 feet
Charted.....			300 feet
Missiles thrown, up to.....			1125 feet
Glass broken, up to.....			$\frac{3}{4}$ mile

HERODSFOOT, ENGLAND

Chart No. 120

A severe explosion occurred at a gunpowder factory at Herodsfoot, Cornwall, England, on May 12th, 1876, at 11:00 A. M.

The explosion originated in the breaking house, which contained only about 200 pounds of powder, but involved the cake house, containing 4 to 4½ tons, the press house with 400 pounds, and the mill, which contained only a single charge, or 60 pounds. It was estimated that a total of 9000 pounds of black powder was involved.

The breaking house was a stone building 23 feet long by 16½ feet wide by 8 feet high. The walls were 18 inches thick, and lined with wood. The roof, which was of slate, was not lined. The building was built into an excavation in the side of the hill, and an earth mound was thrown up in front and on the sides.

Only 55 feet away stood the cake house. It was completely screened by a substantial mound of earth. The building was of stone, wood-lined, with a roof of deal timber covered with 12 inches of clay, and slates on top of that. It was also built in an excavation about 25 feet high at back, sloping on the side down to about 10 or 12 feet.

The press house stood about 155 feet from the cake house, screened by the earth barricade and the dip in the ground. It also was stone, wood-lined, with a slate roof. About 320 feet from the cake house was the incorporating mill, another stone building, with a felt roof, and open front and back.

The first explosion was the breaking house. This explosion was followed after an interval of 15 seconds by the big explosion in the cake house. Two

men in the cake house saw the flash in the breaking house, and were able to run 80 or 90 yards before the cake house went, when the shock from the latter explosion blew them down. Also the foreman saw the breaking house go, and had time to screen himself before the cake house explosion. Set off by the second explosion, the contents of the press house and mill exploded in a few seconds, almost simultaneously, although the foreman distinguished four explosions.

Three lives were lost. One man near the press house was killed at once, and two men in the breaking house were so badly injured that they died in a few hours.

One of these men was able to give the cause of the accident. The operation in which they were engaged was that of breaking up the press cake preparatory to placing it in the corning sieves for reduction to grains. In order to do this, the press cake is placed on blocks of hard wood and struck with wooden mallets. One of the dying men distinctly and emphatically stated that fire had been struck from his mallet while he was carrying on this work.

The cake house was completely destroyed, and a deep crater filled with water was the only thing which marked the site. The breaking house was demolished, but parts of the walls were standing, and no crater was formed, as the quantity of powder in the building was small. The press house was thrown down, and the machinery displaced, but the foundations were not affected. The roof was blown off the incorporating mill, and some of the woodwork was injured. A mill, separated from this one by a double wall and intervening water wheel, was not exploded.

The damage done to other buildings in the factory was as follows:
Empty cask house, 280 feet from cake house, unroofed.

Granulating house, 300 feet distant, unroofed, and roof beam cracked.

Sifting house, 500 feet away, window broken and slate injured.

Glossing house, about 690 feet away, slates disturbed and door broken.

Stove, 560 feet from the cake house, slates blown off ceiling fractured, window frames broken, and sashes blown in.

Stove, 450 feet from the cake house, the same damage.

Boiler house, 450 feet distant, roof damaged.

Packing house, 330 feet distant, almost entirely unroofed, windows and sashes broken, door broken in.

Charge house, 430 feet from the cake house, slate roof slightly injured.

Cooper's shops, 320 feet away, window frames broken, roof badly damaged.

Foreman's house, 250 feet from cake house, had its roof and several joists destroyed, nearly all windows blown in, ceilings destroyed, floors split in two, and the house rendered uninhabitable.



EXPLOSION
HULL, P.Q. CANADA
May 8th, 1910

0 500 1000
SCALE FEET

Store magazine, 530 feet from the cake house, had slates shaken off, ceiling injured, door frame damaged.

Up to 450 feet damage which may be called serious was effected, but the greater part of the buildings of the factory, which occupied an area of about eight acres, sustained some injury, although the factory was favorably situated in a wooded valley with well-grown trees, which no doubt afforded additional protection.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Factory buildings	Barricaded	Roofs damaged, doors blown in	450
Area of structural damage.....			450 feet
Charted.....			450 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			No record

HULL, CANADA

Chart No. 116

An explosion occurred on an explosives factory near Hull, Canada, on May 8th, 1910, at 5 P. M.

The works were located on a strip of land 500 to 600 feet wide, lying between the Ottawa-Montreal Branch of the Canadian Pacific Railroad and a slough of the Ottawa River, about half a mile north of Hull Station. The plant consisted of six or seven buildings, within 100 feet of the railroad, bunched together on less than an acre. All of the buildings were frame construction with exception of the magazine, which was built of stone with walls 24 inches thick (a requirement of the Explosives Law of Quebec) with tin roof. The buildings of the plant were all unbarricaded and appeared to be as follows:

- Watchman's shack
- Mixing and Packing Buildings
- Office (evidently also used for storage purposes)
- Soda Dry House (open shed)
- Chlorate of Potash Store House
- Magazine

About five o'clock on Sunday afternoon, May 8th, 1910, a fire started in the shack of the watchman, who at the time was away in the neighborhood getting supplies. The fire communicated to the other buildings and

in about forty minutes the first explosion (small) occurred, being immediately followed by explosion of the contents of the magazine. Indications were that the first explosion was powder in bulk in the Packing House in end of building nearest the magazine. It was reported, however, that the first explosion was some detonators stored in or near the magazine; exploded and unexploded electric fuzes were scattered around in the hole made by explosion of the magazine.

The explosives product was a Chlorate of Potash compound called "Virite," and at the time of the explosion the magazine is reported to have contained 9,500 pounds of this powder packed in fifty pound boxes.

As a result of the explosion and fire, the entire plant was destroyed. The only building of which anything remained was the Chlorate of Potash store house. The sides and roof of this building were smashed in, but the contents, consisting of about 125 barrels (115 lbs. each) of Chlorate of Potash were in very good shape, only a few of the barrels showing broken sides.

Strewn about the site of the plant was a large quantity of wreckage of all kinds: pieces of machinery, screens, tanks; a quantity of melted and partly burned Nitrate of Soda, smoldering bags of pulp, traces of sulphur and a smoking mass of some tarry substance, resembling Nitrate of Ammonia, originally packed in barrels, and five iron drums which had contained benzine.

The plant was surrounded by a growth of scrub evergreens. The surrounding country being practically the same elevation as the plant, except towards the west in the direction of the Chelsea Road where, after about 600 feet the ground gradually rises until at say 1600 feet it is probably 75 to 100 feet higher than the plant.

DAMAGE TO OUTSIDE PROPERTY. The nearest building to the explosion was a frame dwelling, at the time vacant, distant 300 feet. This house was wrecked. North of this dwelling, 75 feet away, was a frame stable, which had the sides and roof badly damaged, and overshoot wrecked. Located on the side of the slough, 100 feet from the dwelling and 400 feet from the explosion, partly protected by the 18 foot bank of the slough, was a frame building 50 feet by 60 feet, occupied by a fertilizer company. The end of the building towards the explosion had part of the roof damaged, sides torn off and rafters broken.

Directly south of the plant was a frame structure with brick stack containing machinery for cutting stone. This building was on slightly lower ground than the powder plant, distant about 400 feet. The side facing the explosion was completely shattered, the roof badly broken, in fact the entire building was more or less seriously damaged, pieces of the roof, rafters and sides being thrown down inside the building. The brick stack was cracked in two places. Two sheds nearby were wrecked.

Between 400 and 900 feet there were no buildings, but from 900 feet to 2000 feet there were quite a number, especially to the east and west where edges of settlements extended towards the plant. Damage here was entirely due to missiles; huge boulders varying in size from 30 to 40 pounds to over 100 pounds passed through the frame structures as if they were built of paper, badly damaging interior of the houses in many cases. The high velocity at which these stones were going may be judged by the fact that after traveling over 1000 feet they would leave a building at a point higher than that at which they entered. The zone of missiles seems to have been beyond 600 feet, the greatest number striking at about 1200 feet.

KILLED. All the ten fatalities were due to missiles, as follows:

Boy in field west of plant.....	650 ft. distant
Man on railroad track in front of plaster factory.....	1000 " "
Three men near railroad bridge over slough.....	1050 " "
Man at corner Eugene St. and Chelsea Road.....	1500 " "
Two girls in house—Chaudiere St., Hull.....	1500 " "
Man in open.....	1500 " "
Small boy in open—east of plant near Chaudiere St.....	1600 " "

INJURED. It was difficult to determine the exact number injured, reports varying from 15 to 20. As to distances at which people were injured, the nearest was a boy at 650 feet, leg fractured; the farthest away, as far as could be learned, was a girl, slightly hurt by stone which came through side of house, distant about 1800 feet. Many of the injuries were quite serious, loss of limbs, etc., resulting, and in some cases recovery being doubtful.

BROKEN GLASS, ETC. In the city of Hull broken glass was not at all general and not to an extent to be expected; windows were broken here and there in patches, principally in the direction of Ottawa.

In the city of Ottawa glass was broken in the Parliament buildings, and plate glass windows smashed in the business section, a distance of two miles; many reports, however, of broken glass were at a much greater distance.

REMARKS. Owing to a fire alarm having been sounded and to the fact that a baseball game was going on near the scene of the explosion, quite a crowd gathered and in spite of frequent warnings of danger, remained only a few hundred feet away. This seems to have proved fortunate since the missiles to a great extent passed over their heads. Narrow escapes were too numerous to mention.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Quarry building	No barricade	Badly shattered	400

SUMMARY—Continued

Area of structural damage.....	400 feet
Charted.....	200 feet
Missiles thrown, up to.....	3050 feet
Glass broken, up to.....	2¾ miles

BARKSDALE, WISCONSIN

Chart No. 7

There was an explosion at the explosives works, Barksdale, Wisconsin, on July 16th, 1906, at 8:10 A. M., in the nitroglycerin neutralizing house. This was a building of wood-frame construction, equipped with four wooden tanks on the upper floor and a small catch tank and lead and glass filtering funnel on the lower floor. The gutter from the nitroglycerin separating house entered on the upper floor, and there were also two gutters on a lower level leaving the house and leading to the No. 1 and No. 2 nitroglycerin storehouses.

The floors of the neutralizing house were lead-covered, and corrugated rubber strips were laid over the lead to give the men a firm foothold. There was no heat on the building or under the gutters, but the weather was sufficiently warm to preclude the possibility of frozen nitroglycerin.

The neutralizing house backed up against a hillside, and was barricaded with heavy log cribs, earth-filled, on the side towards the nitroglycerin storehouses and powder line. The upper end of the nitroglycerin line was out of sight around the nose of a hill.

At the time of the explosion there were four charges of nitroglycerin in the building, a total of 9,669 pounds. It was evident that a charge of nitroglycerin had been started flowing down the gutter towards the storehouse.

The nitroglycerin as far as known was neutral, and there were no slums or mud in the neutralizing house. No definite cause for the accident was advanced.

As a result of the explosion, not a trace of the neutralizing house remained. The crater in the ground was about 40 feet across and 5 feet deep, and a hole was cut in the hillside 8 to 10 feet deep. The barricades, 16 feet wide at the bottom, were completely blown away, one log being thrown 500 feet, and piercing the roof of a dynamite mixing house. The separating house, 300 feet away, protected by the nose of the hill, had the roof and one side much broken up. The apparatus was not damaged, although the empty separating tank was moved six inches. The earthenware spigots were intact.

The roof of the waste acid store, distant about 350 feet, on a higher level and protected by the hillside, was caved in. A man claimed that he

was blown through one of the windows of this house by the force of the explosion.

At the power house, 850 feet distant and on the upper level, partially protected by the hillside, the brick stack was uninjured, but the breaching of the boilers was caved in. Steam was kept up long enough, however, to complete acid operations and fill the water tank. Partition wall and eaves of the building were considerably sprung, and some of the wooden purlins cracked. Apparatus was uninjured.

Damage to the nitroglycerin line and powder line buildings, other than above mentioned, consisted of broken doors and windows.

In the safety area, the roofs of two buildings, 1000 and 1200 feet distant respectively, were sprung, and one building 1400 feet away had a side wall pulled out of place; but these damages were of a minor nature, and could be readily repaired.

Missiles were thrown to a distance of 500 feet.

The glass breakage on the works, over an area of 2500 feet, was general, and there were a few instances of glass breakage in the towns of Ashland and Washburn, about 6 miles away.

In this explosion three men were killed, the superintendent of the works, and two operators in the neutralizing house. The superintendent had left the neutralizing house, and was walking along beside the gutter leading to the nitroglycerin storehouse, and was killed by the explosion, which extended down the gutter about 100 feet.

There was no one else injured.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Power house	Barricaded	Boiler breaching caved in; partition wall and eaves of building sprung; purlins cracked	850
Area of structural damage.....			850 feet
Charted.....			850 feet
Missiles thrown, up to.....			500 feet
Glass broken, up to.....			6 miles

PITTSBURGH, PA.

Chart No. 112

There was an explosion at Acme Powder Plant, about fifteen miles from Pittsburgh, Pa., on March 23rd, 1894, at 7:15 A. M. The explosion occurred

in the dynamite packing house, a two-story frame building, 20 x 85 feet, covered with shingles. This building had no barricades.

The plant was situated in a narrow valley about 200 feet wide to the east of the Alleghany River, running in a general direction at right angles to the river. Black Run flowed through this gorge. The hills on each side of the ravine were about 200 feet high. All the buildings on the plant were of light wood-frame construction.

In the west end of the packing house, at the time of the explosion there was stored about 10,000 pounds of 33% dynamite. In this same building two men were employed in punching the dynamite into paper shells, and on the second floor, two girls were employed manufacturing the shells. All four were torn to pieces by the explosion.

The boarding house, which was a two-story six room house located about 150 feet from the explosion, collapsed, fatally injuring the house-keeper, who died on the way to the hospital.

The cause of the explosion is unknown. Onlookers described it as a bright burst of light blue flame, immediately succeeded by a very violent explosion.

The location of the packing house was at bend of the stream on its left hand bank. A small frame storehouse at the mouth of the ravine, about 500 feet from the packing house, had one side collapsed by the explosion. Two buildings nearby were not materially injured.

On the opposite side of the run, about 90 feet from the packing house, connected by a bridge, was the incorporating or mixing house. In it were stored 600 pounds of dynamite, and 600 pounds of nitroglycerin. This building was not materially injured by the first explosion, but an hour afterwards the contents exploded, following a fire due to falling debris.

The boiler house, up the gorge and about 150 feet from the packing house, was crushed by the explosion. A man, who had just left this building, was stunned.

Still further up the gorge, 300 feet from the packing house, was the building where the nitroglycerin was manufactured. This building was injured inside by the air blast from the first explosion, but neither the walls or roof were damaged.

A storehouse further up the gorge on higher ground was not perceptibly injured.

Three men about 300 feet from the explosion saw the flames, two were uninjured, but one was slightly cut by a piece of flying debris.

There was considerable debris scattered about the plant and the greatest distance to which missiles were thrown was about 1000 feet.

On the opposite side of the river, about a mile from the explosion, a good deal of glass was broken. Two miles north of the explosion, in the

direction in which the wind was blowing, some stained glass was broken in a church.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Storehouse	No barricade	Side collapsed	500
Area of structural damage			500 feet
Charted			250 feet
Missiles thrown, up to			1000 feet
Glass broken, up to			2 miles

REGENT'S PARK, LONDON

Chart No. 81

In the year 1874, an explosion took place in a canal boat, on Regent's Park Canal, London.

The canal boat was in a cutting and partially under a bridge which carried a road over the canal, so that the neighborhood was well screened. No details of the explosion are recorded, except that 10,000 pounds of black powder was in the canal boat at the time.

The range of serious structural damage was 600 feet, minor structural damage 1200 feet, and windows and doors broken up to 1800 feet. Glass was broken up to the distance of a mile. The explosion was heard for 15 miles.

No one was killed or injured in this explosion.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwelling	Screened by location	Serious structural damage	600
Area of structural damage			600 feet
Charted			600 feet
Missiles thrown, up to			No record
Glass broken, up to			1 mile

BELOEIL, P. Q., CANADA

Chart No. 52

There was an explosion in the explosives works at Beloeil, Canada, on January 17th, 1910, at 2:05 P. M.

The explosion occurred in the nitroglycerin nitrating house No. 1,

which was unbarricaded. There was in the building at the time one charge of nitroglycerin in one separator being skimmed, and two charges in the wash tanks, while 6000 pounds was down below in the storage boxes; in all, 12,000 pounds of nitroglycerin.

At about 1:50 P. M. on the day of the explosion, two nitroglycerin workers and the "Schneider" man ran from the nitrator to the yard, reporting that the nitroglycerin building was on fire. Upon viewing the building from a distance of about 400 feet, it was seen that fumes were issuing from the ventilator, and it was decided that it was unsafe for anyone to approach the building.

Workers in the gelignite department buildings, situated from 470 to 600 feet on the far side of the nitrator house were warned by telephone, but the message had no sooner reached them than the explosion took place.

The first, second and third charges had been separated and washed; the fourth was separated and skimming had just been commenced. One of the workers in the house noticed a flame coming through the floor at the point underneath which was a gutter. He raised his skimmer and shouted to the other workman who was on the ground floor, and when he arrived at the stairs, he was met by the flame, which spread almost the whole length of the gutter. The man who was on the second floor had to leap over the flame in order to get downstairs. The two men warned the "Schneider" man, and all three ran to safety.

It was believed the gutter must have overflowed some of its contents on the floor, and that the acid and the nitroglycerin had been gradually decomposing until the heat was sufficient to cause the wood and nitroglycerin to burst into flame. The fact that the gutter was covered with wood and rubberoid would be sufficient to prevent fumes being noticed, especially as this part of the building was never free from fumes during working operations. Had there been a method of flooding the floor, it was just possible that the catastrophe could have been averted.

The nitrating house in which the explosion occurred was entirely destroyed. No one was killed in the explosion, and there were no serious injuries except that one man in the gelatinizing house, 490 feet away, lost his eye from a cut.

The structural damage was as follows:

Nitrating house No. 2, barricaded, 560 feet away, had its roof beams broken, windows broken, wall slightly bulged, and the nitrator and separators moved 2 inches.

The covered passages were partially destroyed and badly twisted.

The gelatinizing house, 490 feet distant, had one side thrown out and all windows broken.

The gelignite mixing house, 630 feet distant, had windows broken and walls cracked.

The gelignite packing house, 890 feet away, had windows broken and walls cracked.

The nitrocotton stove, 680 feet away, windows broken and walls cracked.

The nitrocotton store, 500 feet away, galvanized iron badly broken.

The nitroglycerin store, 480 feet away, had the roof and wall next the nitrator destroyed.

The "Schneider" house, 610 feet away, had the roof and wall next the nitrator destroyed.

The acid recovery building, brick, with a truss roof, 1040 feet away, had the roof lifted out of place, and walls bulged and broken at the top.

The acid storage house, 1100 feet away, a frame building, had one side broken.

A mixing house, 860 feet away, was slightly damaged.

The carpenter shop, 1200 feet away, was slightly damaged.

Dwellings, 1480 and 1860 feet away, had windows broken and plaster down.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Acid Recovery building	No barricade	Roof out of place, walls bulged and broken at the top	1040
Area of structural damage.....			1040 feet
Charted.....			520 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			1860 feet

ANTWERP, BELGIUM

Chart No. 2

On September 6th, 1889, an explosion occurred at Antwerp, Belgium, in a factory established for the purpose of breaking up obsolete metallic cartridges.

The factory was situated on a level piece of ground belonging to the city of Antwerp, lying between the Bassin du Kattendyk, the Bassin Africa, and the embankment of the River Scheldt, in the northern portion called Steenborgerweert.

The factory consisted of three sheds in succession, all rectangular in shape, constructed of corrugated iron with a wooden roof. The first was

divided into two unequal compartments by a longitudinal partition; in the larger of these, the cartridges not yet broken up were stored in wooden boxes, and in the smaller compartment the cartridges were unpacked, and the bullets extracted from them.

The next, or middle shed was also divided in a similar way into two compartments, one being used as a miscellaneous store for the bullets, empty cartridge cases, etc., and the other for emptying the powder from the cartridge cases, sifting it and packing it into boxes.

In the third shed there was the furnace for melting the lead and burning the caps out of the empty cases, and a vertical boiler and engine for driving the machine used for flattening the empty cartridge cases, which were put in stacks for sale.

At the back of these sheds, and at a short distance from them, was the gunpowder magazine, surrounded by an embankment.

In the immediate neighborhood of the factory were the following buildings:

A shed for storing guano, etc., distant about 60 feet only.

Three tanks with pumping engines, etc., for storage of petroleum, the nearest distant about 186 feet.

Two large stores for the storage of petroleum in barrels, belonging to the town of Antwerp, built of brick, distant respectively 291 and 348 feet.

An open iron shed for depositing goods on the quay of the Bassin Africa, distant about 350 feet.

Two dwelling houses to the right of the factory, distant respectively 300 and 390 feet.

Large old wooden buildings, used as stores, distant about 525 feet.

A group of dwelling houses, with a police station, etc., forming the hamlet of Amstruweel, distant 600 to 900 feet.

It is apparent that the site was most unsuitable for locating an explosives factory. Apart from the fact that it was too near dwelling houses, it was within 300 feet of large petroleum stores usually containing many thousand barrels of oil, a fire in which might at any time lead to an explosion in the factory, or, on the other hand, an explosion in the factory might (as actually happened on this occasion) readily ignite the petroleum in storage and result in considerable property loss.

The factory for the purpose of breaking up obsolete metallic cartridges was established on this site at the beginning of the year 1889. Application was made through the municipal council to the Deputation Permanente of the Province for the necessary authority, but work was commenced while the application was under consideration. The work was stopped on the report that the factory was in an unsatisfactory state. But authority was ultimately granted on certain conditions, and operations were allowed to

commence again. One of the conditions was that the amount of gunpowder kept on the premises should not exceed 300 kilograms, or 660 pounds. Within one month of the granting of authority to operate; that is, on Friday, September 6th, at about 1:45 P. M., the explosion occurred.

There were two kinds of cartridges being broken up; one a bottle neck cartridge similar to the Martini Henri, and the other shorter and nearly cylindrical. Both were central fire. In the former, the bullet was 0.45 inches in diameter, weight 358 grains, and the charge of powder 71.5 grains; in the shorter cartridges, the bullet was 0.575 inches in diameter, weight 500 grains, and the charge of powder 82.3 grains. The greater part of the cartridges were of the bottle-neck type. Allowing for a little loss in emptying, sifting and packing the gunpowder from the broken up cartridges, the estimated average quantity of powder obtained from a cartridge was about 70 grains, or one pound of gunpowder from 100 cartridges. It was also estimated that the cartridges were being broken up at the rate of about a million a week.

The amount of powder involved in the explosion was fixed at 6 tons, or 12,000 pounds. This was based on the operations that have been carried on in the past, and by comparison with effects produced by an explosion at Regent's Park, England, in 1874.

As the cartridges were scattered pretty equally all around the factory site by the explosion, and the boxes in which they were contained were for the most part splintered into small pieces, it appeared that they were stored between two lots of gunpowder. There was no other explanation for their general distribution in every direction, since they could not have been stored in such manner as to surround the gunpowder, divided as it was into two portions about 30 yards apart. The beautiful appearance of the "plume" from the explosion indicated that the powder was not closely confined at the time.

All that remained of the factory after the explosion was the furnace for melting the lead (constructed for the most part of loose bricks) not very seriously damaged, and the boiler and engine, which could both be repaired. These were screened from the other parts of the factory by a large heap of ingots of lead, stacks of flattened cases, etc., which formed an effective protection.

Where the other sheds had stood was a crater of irregular shape, about 195 feet long, and 120 to 150 feet wide. The clay from the crater was not projected any distance, but remained about its edge, some of it in large masses and forming a fairly uniform lip or bank, about 8 feet high. At the bottom of the crater were two independent accentuations of the main crater, each about 12 feet deep below the ground level, and about 150 feet apart. It was clear from the appearance of the crater that the gunpowder which

exploded was not all in the same building, but in two places about 150 feet apart. The position of the depressions indicated that the powder must have been in the cartridge store (the first shed) and in the emptying and sifting shed (the middle shed), and very little, if any, in the magazine.

Taking first the immediate neighborhood of the factory, the structural damage was as follows:

1. The guano shed, distant about 60 feet, was entirely destroyed.

2. The petroleum tanks No. 1 and No. 2, distant about 160 feet and 210 feet from the crater, both of which were empty at the time, were crushed inwards.

These tanks were the same size, about 13 feet in diameter and 24 feet high. They were sunk to a depth of about 8 feet below the level of the ground in an old pit. They were constructed of wrought iron plates about 4 feet wide, rivetted together, the iron being about 5-16 inch in thickness in the lower plates, decreasing toward the top. The tops were blown off and broken up, parts of both of them being carried towards the factory.

No. 3 tank, distant about 390 feet from the crater, was a much larger one, being about 65 feet in diameter and 36 feet high. It was of similar construction, but not sunk like the others. The wrought iron plates were 4 to 6 inches wide. This tank was crushed in at the top, leaving only two plates at the bottom quite intact all around.

Buildings which were situated between tanks Nos. 1, 2, and 3, consisting of a pumping house with tank, for filling barrels, cooperage, engine and boiler house, office, etc., were all more or less destroyed.

3. The two petroleum stores of the town, distant respectively 285 feet and 345 feet from the crater, were both set on fire and continued to burn until consumed, small explosions of the barrels taking place from time to time.

4. The storage shed on the quay of the Bassin Africa was very little injured. Being an open shed, it offered no great resistance to the rush of the gas, and the damage was mostly confined to broken glass in the roof, and the destruction of the fascia and ornamental work. The shed stood on raised ground about 12 feet higher than the site of the factory.

5. Two dwelling houses to the southwest of the factory, distant respectively 300 feet to 390 feet were both damaged; of the first, only a portion of the wall about 6 feet high remained. The second, an estaminet, was under the parapet of the fortifications and sustained very little structural damage other than the roof blown off.

In the same direction, a substantial old square building, the flat roof of which was covered with turf and scarcely higher than the parapet close by, was only a little shaken at the right hand corner. It was distant from

the factory about 600 feet. A sluice house a few feet farther off was uninjured.

6. Some old wooden timber sheds, distant about 525 feet, escaped with very little damage beyond the loss of tiles.

7. The group of dwelling houses, etc., comprising the little hamlet of Austruweel, distant from 600 feet to 900 feet, sustained considerable damage. There was a general unroofing of the building, and some of the walls were cracked, and in a few cases portions of the brickwork fell down.

In addition to the above, the pumping house of the dry docks, at a distance of about 1110 feet, sustained serious damage. The roof was blown off, and the south wall of the portion used for the engine, two bricks thick, was thrown outwards, as also was the east gable. The walls of the portion used for the boiler were cracked. The chimney shaft was uninjured.

This last building was the limit of structural damage, that is, at about 1110 feet. Excepting tiles which were dislodged from roofs up to a much greater distance, and a few minor cracks in walls, there was nothing of importance beyond this in the direction of the town. The north wall of one of the warehouses in the Rue de Cologne, about 3150 feet away, had to be propped to prevent it from falling, but this was an exceptional case. There were very few if any instances of tiles dislodged at a greater distance than 6000 feet.

There was nothing to show the range of the flash of the explosion. A row of seven willow trees at about 360 feet suffered very little; the top of one was broken off, and twigs and branches were broken on the others.

The general breakage of windows extended to 3000 feet; thus on the Quai du Rhin, and in its immediate neighborhood, frames were blown out and nearly every window broken. Beyond this, the breakage was more partial—while some buildings suffered much, others escaped altogether. The windows on the north side of the church of St. Paul, distant nearly one mile, sustained serious damage, but they were much exposed. A few panes of glass were broken in the Cathedral, 6600 feet away. The extreme limit of glass breakage was at Berchem, about 3 miles away.

Leaving out of consideration exceptional cases, the nature and extent of the destructive effects from this explosion, may be fairly set down as follows:

Radius of structural damage.....	1110 feet
Minor damage, window frames blown out, ceiling cracked, etc., up to.....	3000 feet
Windows broken, up to.....	6000 feet

The number of persons killed or mortally wounded was at first largely over-estimated, owing to many fragments of bodies having been found, and

the number of missing not having been accounted for. The number actually killed was given as 95, nearly all of whom were at work in the factory at the time of the explosion. About 130 cases were treated in the two hospitals in Antwerp, of whom about 70 were detained in the hospitals. A number of the injured went to their homes, but in all probability the number injured did not exceed 150 persons.

The cause of the explosion was unknown, but there is direct evidence that it originated in the factory. Two men who happened at the moment to be passing about 100 yards from the place, affirm that before the explosion occurred they heard some sharp cracklings in the factory, which were so significant that they were induced to throw themselves into the Schyn. The explosion followed, and they escaped injury.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Pumping house	No barricade	Roof blown off, wall thrown down	1110
Area of structural damage.....			1110 feet
Charted.....			550 feet
Missiles thrown, up to.....			$\frac{1}{3}$ mile
Glass broken, up to.....			6000 feet

THOMPSON, MINNESOTA

Chart No. 94

An explosion occurred in a magazine at Thompson, Minnesota, at Camp 3 of the Great Northern Power Company, on March 12th, 1906, at 7:45 P. M.

The magazine was built between two rocky ridges running east and west, and was surrounded by a thicket of saplings, from one to four inches in diameter. The surrounding country was rocky hills, well wooded. Some high hills back of the magazine protected the town of Thompson, a mile and a half away to the west, where the shock of the explosion was felt, but no damage done.

The magazine consisted of two sheds made of one inch boards, 8 x 10 feet in size. One shed was used for thawing powder, the other for storage. They stood about five feet apart and the theory was the thawing house went first.

A total of 12,375 pounds of explosives was involved; 6 tons, or 12,000 pounds of 40% and 60% Hercules dynamite, 15 kegs, or 375 pounds of B blasting powder. A few boxes of caps were also in the magazine at the time.

The cause of the accident could not be ascertained; the keeper of the magazine had just left the thawing house and had gone about 300 feet when the explosion occurred. He was unhurt except for bruises, and the jar in being thrown down. No one was killed, but in addition to the watchman, six men were slightly injured; two men in the destruction of the round house 500 feet away, and four were railroad men 250 feet away. There was a ridge of slate rock about ten feet high between the magazine and the railroad track, where the engine and switch shanty stood. The fireman on engine was jammed against the boiler by the explosion. He was on the side nearest the magazine. The engineer was drawn from his side and thrown over to the fireman's side towards the magazine, and was so badly hurt that he was sent to the hospital.

The magazine and thaw house sheds were demolished, and no trace of either could be found after the explosion.

The structural damage was as follows:

The pump house, 500 feet from the magazine, was demolished.

The frame round house, 500 feet away, destroyed.

The switch shanty, about 250 feet away, was set on fire by the heater inside, and burned.

From 1000 to 2500 feet was located the boarding camp which had buildings badly shaken, and a few rafters cracked.

Windows were broken in the engineer's office, about 2700 feet away. The contents of a long shelf in the office was thrown into the center of the floor and a quantity of china broken.

Owing to the hilly nature of the ground between the magazine and Carlton and Cloquet, these towns were not damaged.

The wind was light, and blowing from west to east, and the smoke cloud from the blast took four or five minutes to get to the engineer's office, 2700 feet away.

The pump house and the switch shanty, protected, 250 feet distant, and the round house, unprotected, 500 feet away, suffered to the same extent.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Round House	By nature of ground, rocky ridge, thicket	Roof crushed in	500
Area of structural damage			500 feet
Charted			500 feet
Missiles thrown, up to			No record
Glass broken, up to			2700 feet

COBALT, CANADA

Chart No. 26

On the 18th of May, 1906, at 4 P. M., the contents of a magazine exploded on the outskirts of the town of Cobalt, Canada.

The building measured 14 feet square, and was lightly constructed of wood. It stood on a hill rising about 80 or 100 feet above the general level, and was surrounded by trees. The thick timber and the configuration of the ground were considered as affording protection to the magazine.

The village of Cobalt was a little over two years old in 1906, and up to that time the forest had not been completely cleared from the neighborhood, the remaining trees being chiefly of the coniferous variety, such as spruce, balsam and cedar.

In the vicinity of the magazine a number of lightly built wooden shacks or huts had been run up by laborers, prospectors, and others.

On the morning of the explosion at about 11 o'clock, a forest fire broke out, which eventually reached the trees and bushes which surrounded the magazine and set it on fire, causing the explosion of the dynamite. The approach of the fire gave time to alarm the people living in the houses near the magazine, and there was no loss of life or injury to anyone.

At the time of the explosion the magazine contained 6300 pounds of 40% dynamite, and 6300 pounds of 50% dynamite, contained in cartridges $\frac{7}{8}$ inches and $1\frac{1}{4}$ inches in diameter, packed in 50 pound cases.

Twenty-three houses were wrecked or burned, and 80 or 90 others were more or less injured. The distances of some of these houses from the site of the magazine were given as 420 feet, 477 feet, and 543 feet. There was glass breakage up to a distance of $\frac{3}{4}$ of a mile.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Shacks or huts	Heavy timber	More or less injured	543
Area of structural damage			543 feet
Charted			543 feet
Missiles thrown, up to			No record
Glass broken, up to			$\frac{3}{4}$ mile

WAYNE, NEW JERSEY

Chart No. 163

An explosion occurred at the powder works near Wayne, New Jersey, on April 1st, 1912, at 8 A. M.

The explosion occurred in the glaze mill, and was communicated to wheel mills Nos. 2 and 5. The building was not barricaded. The glaze mill contained 515 kegs or 12,875 pounds of black powder at the time of the explosion. The No. 2 wheel mill was struck by flying debris and exploded about two seconds after the glaze mill, but the No. 5 wheel mill did not go off for at least two minutes, probably set on fire by a brand thrown on the roof or platform.

The exact cause of the accident could not be ascertained. The foreman was at the glaze mill about an hour before the explosion, inspected the powder and found it in good condition to dump, and told the operator to do so. Everything was in good order, and the powder was barely warm. The foreman left the building and went on his regular rounds. Passing the glaze mill later with the superintendent and the carpenter, he could see the operator standing in the doorway with something in his hand, whether a broom or a mallet he could not tell, and then saw him turn and enter the mill. The three men had gone on for a distance of 250 feet when the explosion came. The superintendent was knocked down, and struck by a stone. He died in about an hour from internal injuries. The foreman's leg was broken above the ankle, and cut above the knee. The carpenter escaped with burns and scratches.

The operator in the glaze mill was instantly killed. He had commenced work in that mill only that morning, and had protested against his transfer from the corning house. The night man in the glaze mill said that when he had turned the house over to the operator, the mill was running in good condition. It was the opinion of the foreman that at the time of the accident the operator had started to clean glaze barrels by hammering with a mallet. All of the barrels were fitted with strips of rubber belting, on which the rapping was done. The mill was on fuse powder, so it was not necessary to rap the barrels hard, as very little clinker accumulated with this kind of powder. Carelessness in handling tools may have caused the explosion.

Two men in the saltpeter refinery, were injured slightly, cut by flying glass, making a total with the above mentioned, of two men killed and four injured.

The glaze mill was destroyed, with the exception of the earth embankment up which the incline ran, two motors, auto starters, and a few bearings. The foundations were badly broken and driven into the ground, the line shaft piers broken off, shafting and pulleys bent or broken.

The wheel mills suffered the same damage; both had the roof and rafters blown off, and many rafters bent. The curb was blown off the motor house,

roof was loosened, and the front out of the mill. The machinery was not damaged, nor the walls.

The structural damage on the plant was as follows:

The No. 2 corning mill, 400 feet from the glaze mill behind a frame slat barricade, and protected from the glaze mill also to some extent by the embankment which carried the glaze mill incline, was considerably damaged. All of the 2 by 6 inch studs placed two feet apart in the side of the mill next to the glaze were broken. The side of the building had come in with sufficient force to break a cast-iron pulley on a shaft nearby. The slat barricade was not injured, except that a few of the cross braces were split. A hole had been knocked through by a piece of shafting from the glaze mill.

The corning mill dust collector, a small frame building immediately across the track from the corning mill, but not behind the barricade, was very little injured. One or two studs were split, and some of the siding loosened. The general appearance of these buildings indicated that the damage behind the barricade was more severe than where there was no barricade, which could not be explained unless in some way the air waves were concentrated behind it.

The packing house nearly 500 feet from the glaze mill and not barricaded, except in so far as the brick motor house and the large concrete piers at the glaze mill acted as a barricade, was badly damaged on the side next to the glaze. The side was torn off, 2 x 4 inch studs broken, sash and window frames torn out, and the ridgepole broken. The side away from the glaze mill had sash torn out. There were a few missiles lying around this mill, but mostly fragments of iron. One large piece of gear struck one of the brass car wheels on a loaded car of powder just outside of the packing house, but fortunately did not set it off.

No. 1 corning mill about 1100 feet distant and not barricaded, was very slightly damaged. A few studs were split and iron pulled loose, sash pulled out and glass broken.

Similar damage was done at the press, located about 1200 feet from the glaze mill; the dry house, 800 feet away, the old glaze mill, 900 feet away; and the canister packing house, 600 feet from the glaze, but behind an earth and plank barricade.

The damage to property outside of the works consisted of plaster knocked down and breakage of glass.

Large missiles, such as pieces of machinery, cast iron, etc., were thrown as far as 1300 feet, and lighter missiles as far as 2000 feet.

There was very little wind blowing at the time, only a slight breeze from the southwest.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Corning mill	No barricade	Studs split, iron pulled loose, sash and glass broken, roof damaged, rafters broken	1100
Area of structural damage.....			1100 feet
Charted.....			550 feet
Missiles thrown, up to.....			2000 feet
Glass broken, up to.....			8 miles

CITY POINT, VIRGINIA

Chart No. 28

During the Civil War, at the time of the siege of Petersburg, Virginia, the Federal troops were unloading large quantities of powder and ammunition at City Point. On August 9th, 1864, the docks were aswam with Federals, and two great barges lay at anchor from which tons of powder were being unloaded and stored in the warehouse on the wharves. A Confederate secret service man smuggled on to one of the barges an "infernal machine", consisting of a set of clock works, which at a given hour would release a pin which would strike a percussion cap and explode 12 pounds of powder contained in a box. The explosion of the powder, not less than 8 tons, (16,000 pounds) in the barges, followed in due course. About 300 feet of the wharves and warehouses were destroyed, but some light wooden buildings and tents, 495 feet away, were only blown down.

About 58 Federal troopers were killed, and 126 injured by flying debris. Fragments of the barges were thrown 1500 feet.

The two following reports, taken from the Official Records of the Civil War, are interesting in this connection:

REPORT OF JOHN MAXWELL, SECRET SERVICE, CONFEDERATE STATES, OF EXPLOSION AT CITY POINT

Richmond, December 16, 1864

"CAPTAIN: I have the honor to report that in obedience to your order, and with the means and equipment furnished me by you, I left this city 26th of July last, for the line of the James River, to operate with the horological torpedo against the enemy's vessels navigating that river. I had with me Mr. R. K. Dillard, who was well acquainted with the localities, and whose services I engaged for the expedition. On arriving in Isle of Wight County, on the 2nd of August, we learned of immense supplies of stores being landed at City Point, and for the purpose, by stratagem, of introducing our machine upon the vessels there discharging stores, started for that point. We reached there before daybreak on the 9th of August

last with a small amount of provisions, having traveled mostly by night, and crawled upon our knees to pass the east picket line. Requesting my companion to remain behind about half a mile, I approached cautiously the wharf, with my machine and powder covered by a small box. Finding the captain had come ashore from the barge then at the wharf, I seized the occasion to hurry forward with my box. Being halted by one of the wharf sentinels, I succeeded in passing him by representing that the captain had ordered me to convey the box on board. Hailing a man from the barge, I put the machine in motion and gave it in his charge. He carried it aboard. The magazine contained about twelve pounds of powder. Rejoining my companion, we retired to a safe distance to witness the effect of our effort. In about an hour the explosion occurred. Its effect was communicated to another barge beyond the one operated upon, and also to a large wharf building containing their stores (enemy's) which was totally destroyed. The scene was terrific, and the effect deafened my companion to an extent from which he has not recovered. My own person was severely shocked, but I am thankful to Providence that we have both escaped without lasting injury. We obtained and refer you to the inclosed slips from the enemy's newspapers, which afford their testimony of the terrible effects of this blow. The enemy estimates the loss of life at 58 killed and 126 wounded, but we have reason to believe it greatly exceeded that. The pecuniary damage we heard estimated at \$4,000,000, but of course we can give you no account of the extent of it exactly.

Very respectfully, your obedient servant,

John Maxwell."

THE REPORT OF MAJOR GENERAL RUFUS INGALLS, U. S. ARMY,
CHIEF QUARTERMASTER ARMIES OPERATING AGAINST RICHMOND
OF OPERATIONS JULY 1ST, 1864, TO JUNE 30TH, 1865

Headquarters Armies of the United States,

Washington, D. C., September 28th, 1865

"On the 9th of August near noon there occurred a fearful explosion in the midst of the City Point depot, killing and wounding some 250 employees and soldiers, throwing down over 300 feet in length of warehouses, and tearing up some 180 linear feet of the wharf. It was found that a barge laden with ordnance stores had been blown up. Immense quantities of shot and shell were thrown into the air, and much of it fell into the encampment of the lieutenant general, wounding, however, only one, Colonel Babcock, of his staff. The lieutenant-general himself seems proof against the accidents of flood and field. It was assumed at the time that the explosion was the result of carelessness on the part of someone in or near the barge, but the developments made in the trial of the assassins of the late President would show that it was the dastardly work of that infernal rebel torpedo bureau in Richmond. The damages of the depot were soon repaired."

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Light wooden buildings	Water	Blown down	495
Area of structural damage.....			495 feet
Charted.....			495 feet
Missiles thrown, up to.....			1500 feet
Glass broken, up to.....			No record

STEELTON, PA.

Chart No. 90

A disastrous explosion occurred on May 11th, 1905, at about 1:40 A. M. on an east-bound freight train of the Pennsylvania Railroad at Steelton, near Harrisburg, Pa.

The Cleveland and Cincinnati Express due at Harrisburg at 1:30 A.M. left Philadelphia a few minutes late on the night of May 10th-11th. It was composed of a heavy passenger engine, combination passenger car and baggage car called the smoker, one passenger day coach and six Pullman sleeping cars. The train was made up in this order, and all the cars were vestibuled. As the train approached the Harrisburg city limits it was probably running at a speed of over 50 miles an hour, as it was a little late and the track at this point is well adapted for fast running.

Just east of the city limits, the railroad runs about north and south, parallel to the Susquehanna River, about 200 feet from the edge on an embankment 18 feet high. There are six tracks at this point, and counting from the river, they are used for the following movements:

- 1st. Eastbound passenger.
- 2nd. Westbound passenger.
- 3rd. Eastbound freight.
- 4th. Westbound freight.
- 5th and 6th. Freight shifting and storage sidings.

The passenger express was running normally on track 2, and an east-bound freight train of 68 cars was on track 3. The switching engine without cars was near Steelton on track 3, ahead of the freight train, and one of the crew of this train is said to have flagged the freight at about the time that the passenger train was passing the head end. In stopping, the air application was for some reason so sudden as to cause the buckling of the freight at about the middle.

The airbrakes of the first 34 cars were connected and in service. The

35th was the non-air car. The 36th contained explosives, 400 cases of 50 pounds each, or a total of 20,000 pounds of "Rock Chief powder." The 37th car contained firebrick. The cars on the freight buckled at the powder car, and its rear end, and the head end of the firebrick car were thrown across the westbound track in front of the passenger train, which ran into the side of the powder car, ripping it to pieces, and scattering the powder.

The passenger train was derailed and diverted towards the river. The engine ran for about 275 feet and stopped, turning over on its side. Car 1, the combination car, rolled down the embankment, stopping about 200 feet north. Car 3, the head Pullman, in some manner went beyond cars 1 and 2, and stopped on the slope about 250 feet north.

It is a generally accepted fact that these cars had come to rest and that the passengers were generally endeavoring to get their belongings together and to escape from the cars, when a powerful explosion occurred, which broke all the remaining glass in the cars, blew in the floor and took the roof off at least one of the Pullman cars. The wreckage took fire, and all the passengers who were stunned by the explosion, or pinned down by the wreckage, were burned to death.

Nineteen people lost their lives and 185 were injured, all of whom were on the two trains. The last sleeping car was about 400 feet from the explosion, and six or seven of the passengers in it were severely cut or bruised, but none of them were killed.

After the explosion above described there were at least two minor explosions which probably added to the casualties and certainly added to the horror and confusion. That the heaviest explosion did not occur until from two to five minutes after the collision was definitely determined by reliable witnesses. One of the men on duty at the Paxtang Light Company heard the wreck, ran upstairs to the second floor, crossed the building to the telephone, advised the central telephone office of the wreck, and returned to the lower floor before the explosion occurred which blew in the windows of this building.

The fact that there was an interval of two to five minutes duration is an important one. It proves that the shock of the collision did not explode the powder, and would indicate the rapid attack of fire, which must have communicated to the scattered powder, burning and exploding part of it.

Only a part of the whole cargo of powder in the car exploded, as was shown by the fact that there was no crater to speak of, and that nearby buildings were only slightly damaged.

It was concluded that the powder car was struck by the engine, the powder was scattered along the tracks, fire from the engine was communicated to this powder, which burned, and when sufficient heat was generated, an explosion took place. This explosion did not extend to all the powder,

but scattered some of it about the wreck. This afterwards took fire and exploded at intervals. Some unexploded powder was also found in the wreckage.

The entire passenger train and 12 cars in the freight train were destroyed as a result of the explosion.

There was very little damage to the property of others.

The Paxtang Electric Light Plant, 550 feet away, had windows shattered; the Elliott-Hatch Book Typewriter Plant at about the same distance had glass and sash broken. The explosion overturned a lamp in a house a quarter of a mile away, causing its destruction by fire. Window lights were generally broken within a radius of a mile.

The shrubbery along the river's edge for about 250 feet directly opposite the explosion was stripped bare of leaves by the movement of the gases in that direction. All the pieces of powder cases which were found were located in this triangle, having this part of the river bank as its base and the point of the collision as its apex.

There was little or no wind at the time of the explosion.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Power house	No barrier	Windows broken	550
Area of structural damage.....			550 feet
Charted.....			275 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			1 mile

KELLOGG, ILLINOIS

Chart No. 108

There was an explosion on a black powder plant at Kellogg, Illinois, in the year 1891.

The explosion originated in the glaze mill. This building was surrounded by a wooden barricade, and contained about 20,000 pounds of powder. The actual cause of the explosion was unknown, but it appeared that the powder had been dried and dumped on the floor under the glaze barrel.

The packing house, 500 feet from the glaze mill, was moved slightly on its foundation, and the corning mill, 450 feet away, was moved about three inches in the direction away from the glaze mill, and the frame inclined four or five inches at the base. Roofs were loosened on nearly all the

mills on the plant. Practically all the windows on the plant were broken, and a few windows in houses as far away as 1300 feet.

The powder magazine, which was 800 feet from the glaze mill, contained 7600 kegs of powder piled principally in one end of the building. The magazine was 30 by 50 feet, constructed of 2 x 10 floor joists resting upon 6 x 8 timbers as sills, which were supported by four longitudinal walls, without end walls. On top of the floor joist was a one-inch sub-floor, with a common yellow-pine tongue-and-groove covering. The sides were constructed of 2 x 6 studding nailed to sills, and passing up through the floor, which was tightly fitted about the studding, and on the outside of this studding were one-inch roof boards put on diagonally and covered with corrugated iron; plates 2 x 6 supported a 2 x 6 rafter, common roof-boards covered with sheet iron. The height of the studding was about 9 inches from the top of the floor to the top of the plate, with a quarter pitched roof.

After the explosion in the glaze, a low order of detonation took place in the magazine. After the explosion, almost exactly one-third of the quantity of powder stored there was picked up within 200 feet of the site, the kegs intact. The magazine floor was all that was left of the building. The roof was blown some little distance, but quite large portions of it were intact. The floor was not injured in any way. Not a single splinter could be found that had been split away from the floor boards. Had there been a real explosion in the magazine, it would have been destroyed. The damage to the magazine, however, was not directly due to the explosion in the glaze mill, and therefore the limit of structural damage was taken as 500 feet, the distance from the glaze mill to the packing house.

Flying missiles in one case at least went as far as five eighths of a mile, across the Ohio River. Other missiles were found 1500 feet from the glaze mill, and one went through the roof of a house at a little more than that distance.

Two men in the glaze mill were killed, and a third man at a distance of 500 feet.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Packing house	Wooden barricade	Moved on foundation	500
Area of structural damage.....			500 feet
Charted.....			500 feet
Missiles thrown, up to.....			3300 feet
Glass broken at.....			1300 feet

HOLMES PARK, MO.

Chart No. 115

An explosion occurred on a powder plant at Holmes Park, Missouri, at about 6 A. M., November 12th, 1908.

The explosion occurred in the glaze mill, which was naturally and artificially barricaded. There was 20,000 pounds of black powder involved in the explosion.

The night watchman on his last round of inspection at about 6 A. M. stopped at the corning mill, glaze mill and packing plant, across the hill about 300 feet from the main buildings. The glaze mill was in operation and the watchman spoke to the night tender of the mill and continued his rounds, at completion of which he returned to the office near the main buildings. As he was warming his hands at the stove, there came a tremor and concussion, and he was thrown forward to the floor by the explosion of the glaze mill.

The cause of the explosion was unknown.

The corning mill, 600 feet distant, was set on fire by the explosion and burned down.

The magazine, 600 feet distant, had the roof pushed down.

The packing house, 600 feet distant, had the roof badly damaged.

A Kansas City Southern Railway train was passing Holmes Park when the explosion occurred, and was just opposite the plant, from 900 to 1200 feet away. The train and passengers received considerable injury. On the side nearest the point of explosion, every window, frame and glass was smashed in. Vestibule connections, iron, leather, and rubber, were torn loose. The Pullman sleepers received the worst part of the shock as they were the nearest to the explosion. The heavy curtains, still down at that early hour, and the double glass, afforded protection to the passengers. The mail car at the forward end of the train had the heavy doors forced in and broken.

About thirty people were injured. The concussion threw the passengers from their seats, and glass cut their faces and hands. There were 17 sent to the hospital, but only one case proved serious—the porter, whose eyes were cut by flying glass.

The night operator in the glaze mill was killed.

Missiles were thrown up to 1000 feet, and glass was broken up to a mile and a half.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Magazine	Barricaded	Roof pushed down	600

SUMMARY—Continued

Area of structural damage.....	600 feet
Charted.....	600 feet
Missiles thrown, up to.....	1000 feet
Glass broken, up to.....	1½ miles

CLE ELUM, WASHINGTON

Chart No. 27

At five o'clock on the afternoon of July 18th, 1908, there was an explosion at Cle Elum, Washington.

On the morning of July 16th a freight car containing 750 kegs of black blasting powder, amounting to 18,750 pounds, arrived at Cle Elum, and at about 2 o'clock the car was transferred by switch engine from the side track of the Northern Pacific Railroad to a siding at the magazine.

At 4.30 P. M. on the 18th, the store manager of the coal mining company which owned the magazine, with a clerk, went to the magazine to attend to checking out the carload of black powder. On the way three laborers were picked up at a mine and taken to the magazine to assist in unloading the powder. The car was standing directly in front of the magazine on the up-hill side, the tracking being located about ten feet away from the magazine. The powder was unloaded from the railroad car by rolling the kegs down a chute into the magazine.

On the arrival of the store manager at the magazine, there arose some occasion to use a hammer and nails, and he went to the carpenter shop to get them. It is not known why they were needed. About the time the store manager could have returned to the magazine, there was an explosion, described as a dull heavy roar followed by a sharp loud report.

There was in the magazine 800 pounds of 60% dynamite, and 485 pounds of 40% dynamite, which, with the 750 kegs of black powder, made a total of about 20,050 pounds of explosives.

The magazine building, well constructed of stone and brick, was completely demolished. The car in which the black powder was loaded had the roof, sides and ends blown away, literally converting it into a flat car. The end of the car opposite that part of the magazine where the dynamite was stored was lifted from the tracks, but the other end remained in place on the tracks exactly as left by the switching engine.

The magazine was located at the foot of a hill one-quarter of a mile from the town limits of Cle Elum. The hill to some extent formed a barricade between the magazine and the main part of the town, and there was a mine dump about 40 feet high and 300 feet long that also protected the

town. Outside of the town limits there had been erected a number of small buildings to the southeast in a valley below the magazine.

The nearest dwelling to the magazine was 850 feet distant on the hill above the magazine, and was in the course of construction. The roof was damaged, and six panes of glass on the side nearest the magazine were broken.

The next nearest dwelling was to the southwest, 900 feet away, occupied by the mill foreman. All windows were broken on the north and east sides of the house.

At distances varying from 1100 feet to 1400 feet from the magazine, there were 26 small dwellings with window glass broken, and some chimneys toppled over the roof.

At a distance of 1650 feet there was a hot-house, nearly all the glass of which was broken, and represented the largest single item of loss resulting from the explosion.

Missiles, consisting of some stone from the magazine, were thrown 1400 feet from where the building stood. The bulk of the brick and stone of the magazine appeared to have crushed into a fine dust.

The six men connected with the unloading were all killed. Three were in the magazine, and very little of their bodies were recovered. The three in the black powder car were found up the hill, the bodies badly burned but not dismembered to any extent.

There was a tent, occupied by a woman and child, within 100 feet of the magazine. Though the occupants had been warned to move, they had postponed doing so, and were unfortunately killed by the explosion.

The mine laborers were inveterate cigarette smokers, and in addition there was general carelessness in handling powder. It was supposed that the accident was caused by the careless act of some individual.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwelling (under construction)	Hill and Mine dump	Roof damaged	850
Area of structural damage.....			850 feet
Charted.....			850 feet
Glass broken, up to.....			1 mile
Missiles thrown, up to.....			1400 feet

WILMINGTON, DELAWARE

Chart No. 154

There was an explosion at the Brandywine Powder Works, near Wilmington, Delaware, on November 11th, 1909, starting in the skin pack

house and involving the prismatic press. The amount of explosive involved was 21,175 pounds of fuse and black sporting powder. The building and equipment were both a total loss.

Three men on the plant were killed, at distances varying from six to twenty-one feet. No one else was injured.

The hills along the Brandywine Creek protected Wilmington, but considerable damage was done to the surrounding powder mill property. Five tram cars and a horse were lost.

The structural damage was as follows:

Special slow fuse building, 270 feet distant, had sides torn off and frames broken.

A pack house, at a distance of 360 feet, was badly wrecked.

A tenant house, 400 feet distant, was badly damaged and siding broken.

A brick storehouse, 500 feet distant, had its roof raised.

Structural damage ceased at 525 feet. Missiles were thrown 75 feet, and glass was broken a mile away.

SUMMARY

Building damaged	Barricaded	Extent of damage	Feet distant from explosion
Plant buildings	Hills	Structural	525
		Area of structural damage	525 feet
		Charted	525 feet
		Missiles thrown, up to	75 feet
		Glass broken, up to	1 mile

TACUBAYO, MEXICO

Chart No. 173

An explosion attended with much loss of life occurred at Tacubayo, Mexico, not far from Mexico City, on August 19th, 1913, at 7.10 A. M.

An American powder company sent a shipment of three cars of blasting and sporting powder to its storage magazine at Naucalpam, to be eventually used in road construction work. On its way it was held up by Mexican officials at the Nonoalco station of the National Lines of Mexico in the town of Tacubayo.

The powder company's agent was first approached by a Mexican captain, who casually asked him to deliver the shipment to the government. The agent asked to see the official orders back of this request, and was referred to the Mexican War Department, who apologized and said it was all a mistake. They said that they had been secretly informed that the

shipment was escorted by Suspicious Persons, but that now it was all right, and the car could go on.

But the car was still held at the station. The agent kept applying for permission to move it on to its destination, but received no satisfaction. After 38 days of delay, an official order was given that the powder could not go on to the company's storehouse, but must be sent to the powder magazine of the Mexican government at Santa Fe.

As railroad connections were not convenient for sending the powder to Santa Fe, it was at first decided to send it by automobiles. Later it was decided to send the three cars of powder from the Nonoalco station to the Colonia station in Tacubayo, and then by electric tram from Colonia to Santa Fe. The Director of the Mexican Government Powder Factory requested that a representative of the American powder company should accompany the shipment, and accordingly a Mexican employee went with the car, which was guarded by Mexican soldiers.

As Mexican trains were not run at night, it was arranged that the train should make the trip between the two stations by day, and the work of transferring the powder from the train to the electric trams should be accomplished during the night, and early on the following morning the shipment would be hauled to Santa Fe, the nearest point to the factory, where it was to be unloaded from the trams, reloaded on carts, taken to the factory and carried in by soldiers.

This was carried out. The contents of two of the three railroad cars were safely carried by trams to Santa Fe, transferred to carts and delivered. At 4 o'clock in the morning, two electric freight cars carrying the contents of the third and last car left Colonia and arrived at Santa Fe at about 5 A. M. Unloading was begun between 5 and 6 o'clock. The first of the electric cars to be unloaded was placed on the track nearest the factory, and the second car was put on a small siding on the main track about 240 feet from the first.

Something went wrong with the brakes of the second car, and it began to slide on the steep grade back towards Tacubayo. The motorman was standing beside the track, and when the soldiers and the powder company's man yelled to him to jump on and stop it, he made an attempt to get on board in front and failed; tried to get on in back, and failed again; and the car, loaded with 1,021 kegs of powder, 22,440 pounds, gathered momentum, traveled down the steep grade at the rate of 120 miles an hour, dashed for about three miles back towards Tacubayo, went off the track and the powder exploded, killing 183 people, wounding over 200, and destroying many houses.

The explosion occurred at Nonoalco, at the end of the town of Tacubayo.

The explosion occurred at Nonoalco, at the end of the town of Tacubayo. Almost every house in the town was damaged, and the explosion was felt all over the district.

When the motorman saw his car speeding down the grade he endeavored to escape but he was pursued by soldiers who fired after him, and finally caught him. He and the other motorman and the unfortunate powder company employee were taken prisoner. The other motorman, being a twelve year old boy, was released, but the other two were walked through the streets with their elbows tied, cast into jail, and held "incommunicado." In the course of three days, the employee was released, and received "a small present in cash from the powder company to salve his feelings for the disgrace of being in jail."

Much damage was done in Tacubayo. Within a radius of 385 feet, houses were almost totally destroyed, and the few walls which were left standing had to be pulled down to keep them from collapsing. In this section there were 13 houses of masonry, and 20 small wooden houses. In general, the houses had stone foundations up to the level of the floor, and after that adobe up to a height of 12 or 15 feet about a foot thick. The roofs were sometimes wood, sometimes tile. All these houses were inhabited by poor people.

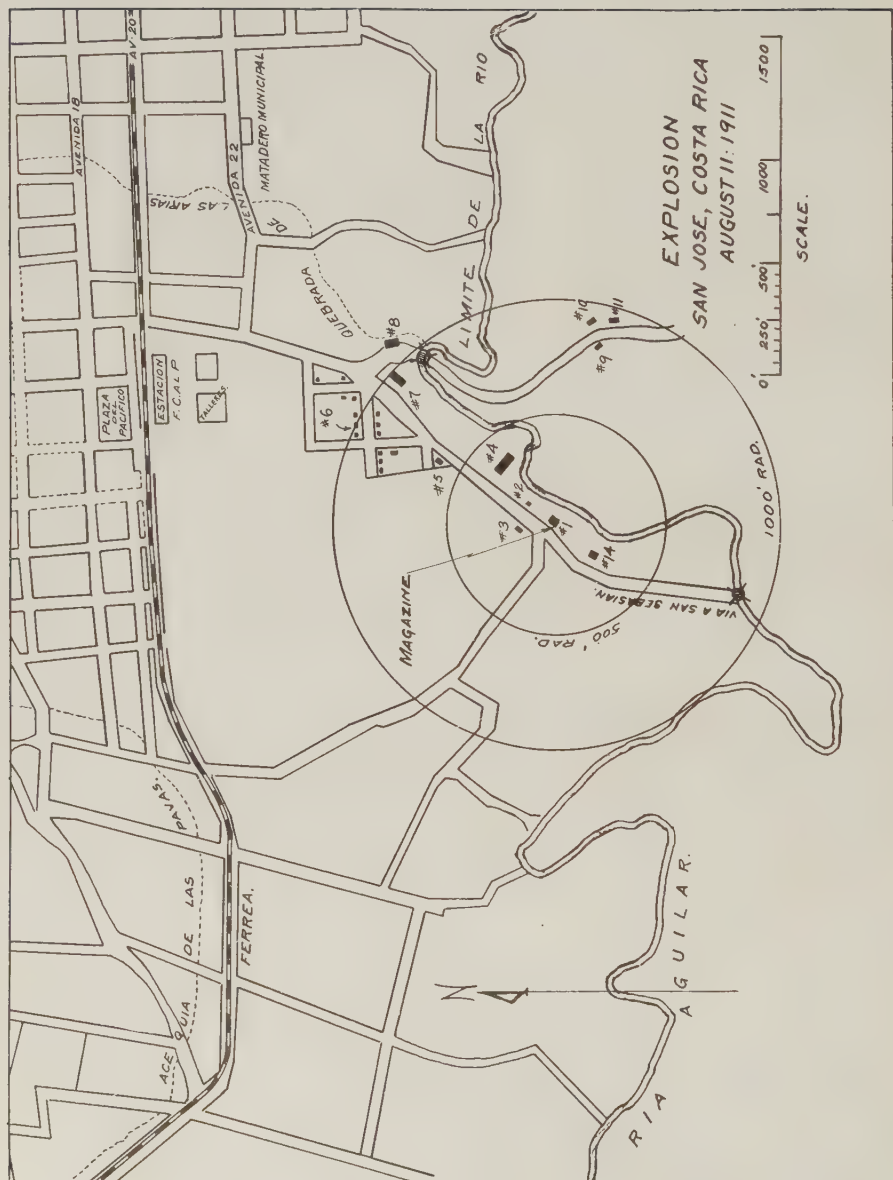
In the second zone, houses within a radius of about 865 feet, serious damage was done, walls bulged out, broken and cracked walls, etc. There were 52 houses injured, of a better type than houses in the first zone.

Within a radius of about 1825 feet, many houses were damaged, windows and doors blown out, cracked walls, sheet iron roofs blown off. They were reported as the "handsome summer residences of wealthy people," and were built of good materials. They were one story houses built 3 or 4 feet from the ground, on an average 15 or 20 feet high.

In the immediate neighborhood the explosion was very much felt. Glass was broken in the town of Mixcoac, two miles away.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwellings	No barricade	Windows and doors broken, walls cracked roofs damaged	1825
Area of structural damage.....			1825 feet
Charted.....			912 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			2 miles



JELICO, TENNESSEE

Chart No. 179

There was an explosion in the town of Jellico, on the boundary line between Kentucky and Tennessee, on September 21st, 1906.

A freight car on a siding of the Louisville and Nashville Railroad in the Jellico yards, loaded with 150 cases of 60% dynamite and 300 cases of 40% dynamite, a total of 22,500 pounds, was rammed by two freight cars loaded with pig iron with such force that the dynamite exploded.

The crater formed by the explosion was about 30 feet deep and about 75 feet wide.

Eleven people were killed; four men in the railroad yards, a man, woman and four children who were passing the freight car at the time, two men on Main Street, 800 feet away, and a negro in a house 1000 feet away, who was killed by a collapsing wall. Over 100 people were injured, mostly by flying glass, which was broken into small pieces and thrown with sufficient force to cut clothing and penetrate the flesh. Most of the injuries were not serious, except in two cases when men's eyes were cut by glass. Two people were hurt by falling missiles.

Jellico, Kentucky and Jellico, Tennessee are connected by a main street about three-quarters of a mile long, with buildings on the west side only; to the east an open space extends 300 feet between the street and the railroad yards. Every building on the street was damaged, not a pane of glass remained, and in many cases the entire fronts of houses were shattered. Structural damage was done at a distance of 1000 feet from the explosion.

The town was situated in a valley, with mountains 1000 feet to the west, and a mile to the east.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwellings	No barricade	Wall collapsed	1000
Area of structural damage			1000 feet
Charted			500 feet
Missiles thrown, up to			No record
Glass broken, up to			No record

SAN JOSE, COSTA RICA

Chart No. 161

At 8 o'clock on the morning of August 11th, 1911, there was an explosion in a government powder magazine within the city limits of San

Jose, Costa Rica, only about 1800 feet from the thickly settled portion of the city.

The magazine was located in a ravine to the south. It was a brick building with walls 12 inches thick, and a corrugated iron roof, surrounded by a small moat 3 feet wide. The eaves of the building were between 4 and 5 feet above the ground on the up hill side, to the north. The dimensions of the building were about 40 by 60 feet, and it was divided into two rooms, separated by a brick wall, with only one opening, which was closed by two doors, one of wood and one of iron. Both rooms had glass windows, protected on the outside by iron bars. There were no barricades.

There was a wire fence around the magazine at about 50 feet away. At the north side it came just at the edge of the road, where there was a small guard house about 4 by 6 feet at the entrance.

An interesting feature in connection with this magazine was that in one of the rooms three or four soldiers lived, slept and cooked, while in the other were stored the explosives. In the magazine at the time were 4,900 pounds of 40% dynamite, not over a year old, 18,220 pounds of black powder several years old but in good condition, making a total of 23,120 pounds. In addition there was 3694 pounds of smokeless powder which had been there since 1897, in doubtful condition. It was a leaf powder manufactured in Spandau.

The explosion was less severe than would be expected from the quantity of powder involved. The commander of the city of San Jose argued that the smokeless powder went off first, from spontaneous combustion, detonating the powder and then the dynamite. Several witnesses agreed that they had seen two distinct columns of smoke, the first white and the second dark brown, and that smoke was seen coming from the magazine before the explosion. The evidence of fire before the actual detonation is fairly conclusive, but from the fact that there were four men in the adjoining room, it is not likely that it could have been burning for any length of time.

The cause of the explosion is of course unknown. The theory of spontaneous combustion was considered reasonable, since the smokeless powder was 15 years old. On the other hand, the accident may have happened through the carelessness of the soldiers as the most elementary rules for safety were violated. The men lived and cooked in the same building with the explosives. Witnesses testified that they had seen the guards smoking, and one man stated that on the day before the accident he had seen one of the soldiers sitting on the roof, which is very low on the uphill side, whittling and smoking cigarettes. An agent sent some years before to destroy some old dynamite in the magazine, so old that it was in a dangerous condition, said that he had found difficulty in persuading the officer in charge to throw away his cigarette at the door of the powder room. He also

said the floor was a quarter of an inch thick in loose black powder, and only by refusing to enter could he induce the officer to remove his nailed soled shoes.

Nothing was left of the magazine but a corner of its brick foundation.

The loss of life amounted to five persons, four soldiers and a child. The soldiers were all in the living room of the magazine. When the fire started, they rushed from the building, but were killed before reaching a place of safety. One man must have distanced the others, for he did not die immediately. The child's body was found on the road, about 200 feet from the explosion, but she may have been much nearer when the explosion occurred.

Three other children were in the road on their way to the city, between 200 and 400 feet from the magazine. One boy on horseback was thrown from his horse and bruised. The horse was also thrown down. The other two boys were slightly bruised by their falls, but none of them were seriously injured.

A house about 200 feet away from the magazine, with no protection between, was entirely wrecked. Of the four occupants, three were slightly injured by falling timber, but the fourth, a man who was standing in the doorway facing the magazine, was uninjured. (No. 3 on the map).

This house was of bamboo and adobe construction, popular as being earthquake-proof. It consisted of a 2 x 4 foot frame, with a $\frac{1}{2}$ to 1 inch bamboo nailed to both sides, and filled between with adobe and small pieces of broken tile. The outside and inside was then plastered to cover the bamboo entirely, and then painted. The roof was wood, covered with 6-inch channel tile, laid loose, making a very heavy roof. This type of roof was abandoned later on account of earthquakes, and was replaced by corrugated iron. The light construction undoubtedly prevented serious injury to the inmates of this house, most of the injury being done by the tiled roof.

No. 4 on the map shows La Algodenera, a cotton storehouse, which was being made over for use as a prison for women. It stood at a distance of 350 to 400 feet from the magazine. This building was of concrete, with walls 18 inches thick, very heavily pilastered. The roof was frame, covered with iron. The roof was blown off, and the concrete walls thrown down and cracked for a distance of about 2 feet from the plate line. The line of damage here seems to be at a point between the protected and unprotected part of the building. There is rolling ground between it and the magazine site, and the undamaged portions of these walls were protected by it.

At the time of the explosion, a number of carpenters were working on this building. The manager stated that he was deafened by the explosion, saw the upper part of the building fall over, and tried to save himself by

reaching the yard in almost complete darkness, for the dense cloud of smoke and dust prevented him from seeing. He was injured in the head, but not seriously, and of the 10 or 12 carpenters at work, 6 or 8 were slightly injured by falling timber or concrete in the building. The rolling ground between the magazine and this building gave protection to the ground floor, but not to the upper part of the building.

No. 5 on the map is an adobe bamboo house, 600 feet from the magazine site, partially protected by high ground between. The only damage to this building was the wrecking of the roof, and the cracking of some of the walls. This building was of the same construction as No. 3, except that it had a corrugated iron roof. In this house three women were injured, painfully but not seriously, by the falling of the roof.

The group of houses marked No. 6 on the map, were built, some of bamboo and adobe, others entirely of corrugated iron. These buildings were from 700 to 1000 feet distant from the explosion, some of them slightly protected, and others not at all. None of these buildings were damaged, with the exception of 2 or 3 sheets of iron in the roofs being loosened and thrown a little out of position, or a few loose tiles.

No. 8 on the map is a saw-mill. It was of frame construction with a corrugated iron roof, 1300 feet from the magazine site, and fully protected. It was not damaged by the explosion, with the exception of two or three sheets of iron loosened in the roof, and thrown out of position.

No. 9 on the map was a frame house standing 800 feet from the magazine, unprotected. This house was entirely wrecked.

No. 10 on the map was an adobe house with 18 inch to 24 inch walls, standing 900 feet from the magazine, but fully protected from it. This house was not damaged.

No. 11 is an adobe house with 18 inch to 24 inch walls, standing 900 feet from the magazine site. The southern part of this building was behind the hill and protected from the magazine, but the northern part was practically destroyed.

The building marked No. 12 on the map is a country club, at a distance of 6800 feet from the magazine. The building marked No. 13 is the office of the United Fruit Company, 5,000 feet from the magazine. These two buildings were the farthest point at which there was a record of glass having been broken. Both the buildings are at the head of ravines, and in the line of least resistance from the magazine. The country club was protected by an intervening hill, but the Fruit Company's office was not.

The thickly settled part of the city began at a distance of only 1800 feet from the magazine. The city, however, was protected by an intervening hill from the site, or the damage would have been more serious than it was. The people in the blocks near the Pacific R. R. Station were considerably

shaken up, badly frightened, and had glass broken in their windows, but no further damage done.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Adobe houses	No barricades	Badly damaged	1000
Area of structural damage			1000 feet
Charted			500 feet
Missiles thrown, up to			No record
Glass broken, up to			6800 feet

VESTAL STATION, NEW YORK

Chart No. 96

There was an explosion in a freight car of the Delaware, Lackawanna and Western Railroad on June 9th, 1901, at about 9:30 P. M., near Vestal, New York.

The accident occurred about 2,000 feet from the railroad station at Vestal.

On the south side of the tracks, the land rises gently. It consisted of grass lands entirely, and there were no houses in sight except to the southwest, where the small village of Vestal, containing perhaps thirty or forty houses, could be plainly seen.

On the north side of the tracks were a number of fields under cultivation from the railroad tracks to the country road, a distance of perhaps 1200 feet. On this road were four farmhouses, the barn belonging to each house acting as a barrier to the force of the explosion. Beyond these houses to the northwest were fields and timbered tracts of land reaching to the trolley road which runs from Union to Binghampton along the south bank of the Susquehanna River.

Train No. 61, consisting of box cars, the car next but one to the caboose containing 24,000 pounds of dynamite, was scheduled to arrive in Binghampton a few minutes after 7 P. M. It was 2 hours late. Just before reaching Vestal, the locomotive was disconnected from the train, and went to the water tank just beyond the station to take water, sending back a flagman to protect the rear of the train.

The locomotive, after taking water, went back to the train, whistled in the flagman, and had just got in motion when a wildcat train with two locomotives on the head end crashed into the rear of train 61, the explosion taking place immediately. The engineers of the wildcat train, both of whom jumped before the accident, claimed that they did not see the lights of

the train, nor hear the torpedoes which the flagman of train 61 claimed that he put on the track before he was whistled in by his engineer. The wildcat train engineers claimed that after rounding the curve they were unable to stop the train in time to avoid the collision. As the distance from the curve to where the accident occurred was about 2,500 feet, it would seem that they could not have seen the train until they were almost upon it.

The head engine of the wildcat train plowed through to the powder car, which was the next car to the caboose. The largest portion remaining of the head engine was the tender and the individual wheels of the locomotive. The boiler, smokestack, box and cab were blown to pieces. The second locomotive was in comparatively good shape. About twenty-five cars on the train were wrecked. The force of the explosion was shown on the south side of the track for a distance of about 300 feet, the earth being entirely swept bare of vegetation for that distance. There was very little damage done to the roadbed of the railroad.

Five railroad employees were killed, and seven injured. Three, and perhaps four, of the victims would have been killed by the collision if there had been no powder on the train, but the fifth man was undoubtedly killed by the explosion.

In the village of Vestal perhaps two-thirds of the windows in all the houses were broken, and one warehouse, which apparently was a very old building, sustained damage to the extent of having sashes blown in, plaster broken from the ceilings, tables and chairs knocked down and china broken. The barns in front of three of the four farmhouses on the country road 1200 feet from the explosion had all the rafters broken on the side towards the wreck, sashes blown in, shingles loosened from the roof and the doors blown in or out.

The concussion of the explosion was felt very distinctly at Binghampton, 8 miles away. Several plate glass store windows were cracked, and the transom of a hotel door was blown out.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Farm buildings	No barricade	Rafters broken.	1200
Area of structural damage.....			1200 feet
Charted.....			600 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			8 miles

YREKA, CALIFORNIA

Chart No. 106

On August 21st, 1906, at 9:55 A. M. there was an explosion at Yreka, California, in a powder magazine situated near the railroad about a quarter of a mile east of the town. The magazine contained 24,300 pounds of explosive, more than half of it being 70% and the rest 40% dynamite.

The ventilators in the building were screened on the outside, but went directly through the rock walls above the flooring, so that it was possible to look through and see the boxes of powder inside the magazine. There were eight of these ventilators, with two others of the same type in the gable at each end of the building, a better location because they were 6 feet above the pile of powder boxes.

Three boys about thirteen years old rented rifles the morning of the explosion, and started out for a hunt. It is probable that the squirrels living under this magazine attracted the boys' attention. A squirrel may have run under the magazine, and one of the boys, perhaps believing that the ventilators were under the flooring, as they were in the other two magazines, may have thrust the rifle through the ventilator and, to scare the squirrel out, fired, causing the explosion.

One of the three boys with a rifle was lying in a hollow about 60 feet from the magazine. This boy, a negro, was picked up in the swale with the gun beside him, with a large hole in his head made by a rock. The other two boys were killed instantly.

The explosion swept away all trace of the stone powder house, tore out a thousand feet of the track of the Yreka and Montague Railroad, destroyed eight spans of telegraph and telephone lines, tore a hole 15 feet deep and 40 feet in diameter where the magazine stood, and shook up the town of Yreka. Chimneys in the town were badly cracked.

A powder magazine 400 feet from the explosion had the roof and walls badly damaged. Two tiers of stone all around the building were loose, some of the rafters were broken, and three sheets of iron on the roof were damaged. As this magazine was five feet below the level of the explosion, the force of the blast was nearly all expended above the top of the door.

Another magazine 700 feet distant, and 10 feet lower than the exploded magazine, had its rafters broken, not from debris, but from concussion.

The report of the explosion was heard at Shovel Creek, 30 miles away, and the earth trembled at Fort Jones, a distance of 18 miles.

Glass was broken at 1320 feet.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwellings	No barricade	Chimneys broken, windows shattered	1320

SUMMARY—Continued

Area of structural damage.....	1320 feet
Charted.....	660 feet
Missiles thrown, up to.....	No record
Glass broken, up to.....	1320 feet

COMMUNIPAW, NEW JERSEY

Chart No. 165

A disastrous explosion took place at Pier No. 7, Communipaw, N. J., on February 1st, 1911. The explosion occurred at noon in the course of transferring dynamite from railroad cars to the "Katherine W.," a powder boat transporting explosives around New York Harbor. At the time there were two cars loaded with dynamite on Pier No. 7, and the contents of the third car had been partially transferred to the "Katherine W.," though evidence points to the fact that some dynamite still remained in the car at the time the accident occurred.

On the "Katherine W." there was also 10,000 pounds of black powder packed in 100 pound wooden barrels, which on the morning of the explosion had been taken from the floating magazine at the Government Explosives Anchorage, Robins Reef. The black powder and the dynamite then being loaded was to be shipped to South America by steamer, which was ready to receive the explosives.

The 10,000 pounds of black powder and the contents of the third car, consisting of 300 cases of 75% strength gelatin, 15,000 pounds, or a total of 25,000 pounds in all, exploded, killing about 25 people, and injuring many others by flying glass.

Of the people killed, 6 were employed on the "Katherine W.," 2 were on board the powder boat "Whistler" tied up alongside Pier No. 7, 75 to 100 feet from the "Katherine W.," where she was to load some half dozen cases of dynamite for trade local to New York. The others killed were either men loafing about the pier or unloading the Norwegian ship "Ingrid," which was also tied up to Pier No. 7 unloading bones, etc., to be used in the manufacture of fertilizer.

The two cars loaded with dynamite on Pier No. 7 within 50 or 75 feet of the "Katherine W." did not explode, though their contents were scattered around the pier.

The cause of the explosion was unknown, but it was thought to have occurred through careless handling of the dynamite. A Polish laborer afterwards stated that he was on dock No. 7 looking for employment when the "Katherine W." arrived, and was hired by the Captain to help unload. He said that after the Captain broke the seal and opened the car door,

1	MINERAL CHARGE
2	MINERAL
3	MINERAL
4	MINERAL
5	MINERAL
6	MINERAL
7	MINERAL
8	MINERAL
9	MINERAL
10	MINERAL
11	MINERAL
12	MINERAL
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96	MINERAL
97	MINERAL
98	MINERAL
99	MINERAL
100	MINERAL

SCALE
1" = 100'

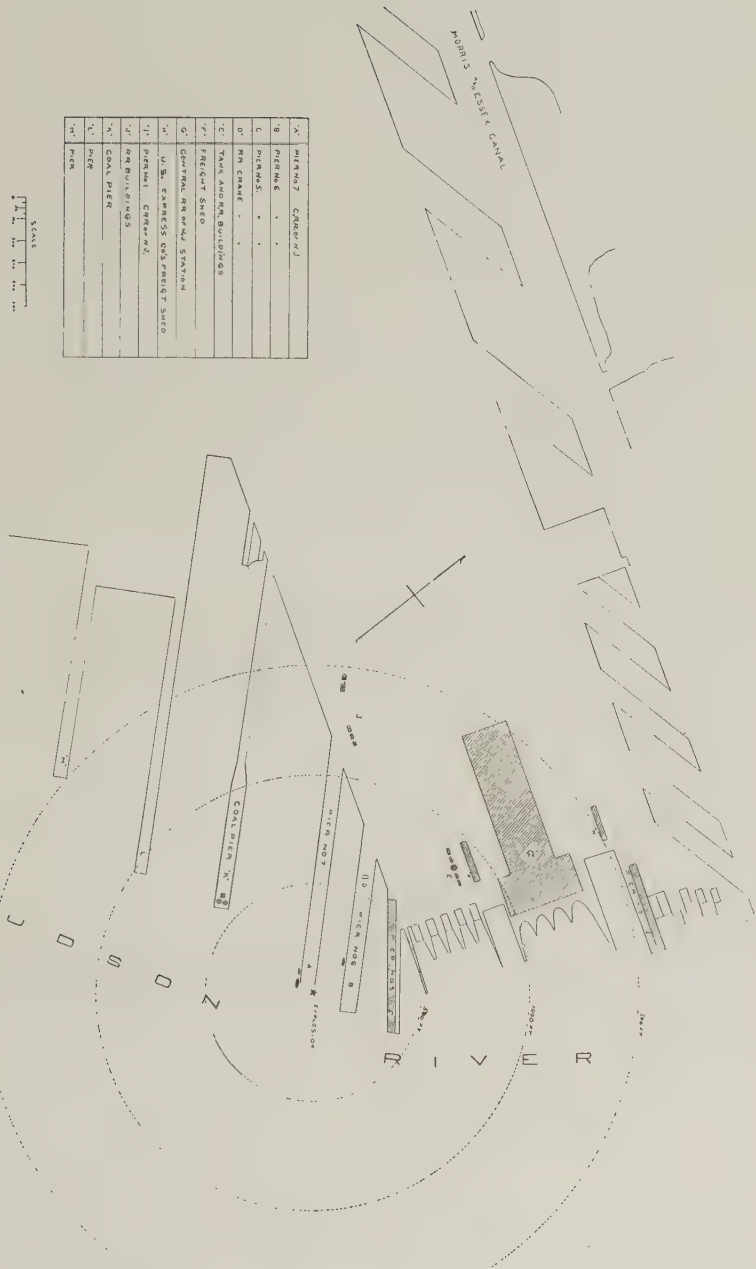
EXPLOSION - JERSEY CITY, N.J.

FEBRUARY 12, 1911.

100'

100'

100'



three men were stationed in the car, one on the wharf stringer outside the car door and two on the deck. A plank about 1 foot wide and 14 feet long, without side guards to prevent sliding boxes falling from it, was placed between the car door and the deck. Two boxes of dynamite were placed under the end of the plank to increase its inclination, as the tide was high. The three men in the car brought the boxes to the plank, and the men standing outside sent the boxes successively down the plank to the boat pushing each box at the start to accelerate its motion. The two men on the deck caught the boxes near the bottom of the plank before they reached the deck, and piled them in a row across the boat. The Captain counted the boxes as they were piled and urged all hands frequently to hurry up the work. The man at the car door shoved the boxes rapidly, and it was often necessary for the two deck men to rush to catch a box to prevent its striking the deck. After work had been in progress for a short time, one of the car men called for a hook to use in handling the boxes. The Captain asked him at first, "What do you want a hook for, do you want to send us all to hell?" A small hook was then passed to him. The speed insisted on by the Captain and the passage of the hook to the man in the car, caused the Pole to protest and then to quit work. He estimated that he had been away about 10 or 15 minutes when the explosion occurred.

It is possible that the falling of one of the boxes of dynamite to the deck could have exploded it and the other dynamite on the boat.

The damage done by the explosion was severe.

Starting from the point of explosion, at the end of Pier No.7 (marked with a star on the attached sketch) within 200 feet there lay the Norwegian ship "Ingrid" and the schooner "B. P. Harwick," and a string of freight cars extending along the railroad track of the pier.

The "Ingrid" within 60 feet (No 1) suffered severely; all woodwork above her deck was shattered, mizzenmast broken, and rigging blown to pieces, with considerable damage to mainmast and rigging, and foremast and rigging. The steel hull did not show signs of damage, the plates were not warped or loosened. The taffrail along her stern in the direction of the explosion was stripped off in places. Her deck was strewn with wreckage, consisting of pieces of timber from the wharf, and a truck and underframe of a freight car.

The "B. F. Harwick" did not receive any serious damage. Her rigging had suffered, but there was no sign of injury to the ship. Protection was afforded her by the pier and railroad cars, as she was tied up about 200 feet from the explosion on the far side of the pier.

Freight cars along the tracks of Pier No. 7 received severe damage. The ones within about 100 feet were shattered, the damage decreasing until at about 300 feet it was slight.

A steel gondola car, which remained on the wharf alongside the "Ingrid" was thrown from the tracks to the edge of the pier, the sides of the car were stove in and a large hole made by a missile, which could not be located. This car was within 50 feet of the explosion, and to some extent must have screened the "Ingrid". On the day following the explosion, this car was shifted about the railroad yard.

A number of barges in the vicinity of the explosion were damaged.

PIER NO. 6, running parallel to Pier No. 7, was 200 feet away. Two freight cars on the end of this pier were badly shattered. Tied up to the pier on the side towards Pier No. 7 was the barge "Emperor", about 225 feet from the explosion. The engine house, a frame affair about 12 x 15 feet x 8 feet high, had three sides and a portion of the roof ripped off, piping and machinery damaged, and the engineer thrown across the engine room, receiving cuts and a fractured skull.

On this pier there was also an overhead crane. The engine house, a frame box-like building about 30 feet above the tracks, and 625 feet from the explosion, had the doors and window frames torn loose.

PIER NO. 5. Along this pier, and extending into the railroad yard about 100 feet, was a freight shed 600 feet by 50 feet. The building was steel frame construction covered with corrugated iron, and extended from 350 feet to 600 feet from the point of explosion. The corrugated iron had been torn from the side facing the explosion to within 50 feet of the land end, this last 50 feet being bulged and loosened, and some of the steel framing in places badly bent, with breaks in some instances. This building received the full force of the explosion.

TANK AND R. R. BUILDINGS, 850 to 900 feet distant from the explosion. These buildings were frame, one-story, two of them old box cars fixed up. Only damage broken glass. The tank had a few places in the top or roof which might have been damaged by the explosion, but it was rotten and in bad repair.

FREIGHT SHED, 950 feet distant from the explosion. Frame, covered with corrugated iron, about 200 feet long by 30 feet, with a second story extending over the half of the building nearest the river. This building had the corrugated iron torn loose or bulged, and studding broken. The roof at the point where the one and two story sections of the building joined, had caved in and a bulge extended along the balance of the roof over this addition.

THE STATION OF THE CENTRAL R. R. OF NEW JERSEY presented a large surface to the force of the explosion.

This building was erected in 1888.

The main station, with train shed and ferry slips, was about 650 feet

long; the station and train shed 225 feet wide, and the ferry slips 350 feet wide, distant from the explosion 1000 to 1500 feet.

The main station and train shed were built of brick with steel roof supports. A slate roof covered the main station; the roof of the train shed consisted of sheet iron and glass skylights, which were thirty to forty feet wide, and extended the length of this part of the station. Inside of the station building, in addition to large skylights, the partitions between the different parts of the building were large windows, glazed. Roughly speaking, there were about 200 windows in the station and train shed in the side towards the explosion.

In consequence of the large extent of glass presented to the explosion, the breakage was tremendous, and showers of glass fell upon people in the station, resulting in a large number of injuries; people exposed to the side windows were also cut by flying glass.

The damage to the station and train shed of a structural nature consisted of sheet iron loosened in the roof of the train shed, and slate dislodged from the roof of the main station. Two courses of brick were also removed in repairing about 50 feet of the train shed wall, giving the impression that the roof had been slightly lifted.

That portion of the station over the ferry slips was of frame construction, covered with tin shingles. The most serious injury here was at the corner nearest to the explosion, about 1000 feet distant. One heavy brace between the uprights and roof supports was broken into two or three pieces; the roof had evidently been lifted, as the tin shingles along the eaves were loosened. A 12 foot by 25 foot lean-to addition at this end of the station had one side torn away where it joined the roof and slanted at an angle of about 75 degrees; the tin shingles were loosened, and the roof showed a decided hump.

One of the partitions between the slips was badly displaced at the bottom, but only required forcing back into position to repair.

U. S. EXPRESS COMPANY'S FREIGHT SHED. This was a dilapidated frame building, 175 feet long by 30 feet wide. There were no signs of damage to this building, except broken glass.

PIER NO. 1. Built along this pier was a frame, one-story freight shed, distant from the explosion about 1600 feet. The damage consisted of doors and window frames blown out, and breakage of glass. The roof at the peak was slightly out of line, but this appeared to be a long-standing defect.

RAILROAD BUILDINGS, between 1100 and 1500 feet distant. The only damage here was broken glass.

COAL PIER, 600 feet from the explosion. Built along and above the pier was a trestle carrying the railroad tracks. Built under this trestle on the end of the pier were two large water tanks. A part of the pier had been

partitioned off. The tanks were not damaged, and were filled with water the day following the explosion. Boards had been torn loose from the partitioned-off part of the wharf, and a large quantity of debris was strewn about the floor of the pier. Some of the braces (planking) between the supports of the tracks above were broken. On the trestle above, a flimsy railing remained intact.

COAL PIERS, 1100 and 1500 feet distant. The only damage here was breakage of glass.

ELLIS ISLAND, 2000 feet distant. Considerable glass broken.

BROKEN GLASS. A mile practically covered the area of broken glass. In Jersey City in the neighborhood of the Pennsylvania Station, along Montgomery Street, there was considerable glass broken, in many cases heavy plate glass; but beyond a mile, this sort of damage was very slight.

In New York, across the river, the breakage of glass was not at all general, but scattered here and there, in every instance large windows being broken. A window on a level with the street would be broken, while those in tall buildings which had no protection, were not.

MISSILES. As far as could be found on land, there were no missiles, with the exception of those thrown on the Norwegian ship "Ingrid", which was located close to the point of explosion. Later developments brought out the fact that a number of missiles were thrown out into the Hudson River.

At the time of the explosion there was a light wind, about 6 to 10 miles an hour, from the East to Northeast. The weather was clear, and the temperature was 32 degrees.

The powder loaded in the "Katherine W." was on deck, two or three feet above the water. That portion of the dynamite remaining in the railroad car was not screened from the surroundings.

The limit of structural damage from this explosion can be put at 1200 feet, with broken glass at about a mile, though of course scattered here and there were cases of damage of this sort at a greater distance.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Railroad station	No protection	Roof lifted top bricks loosened	1200
Area of structural damage			1200 feet
Charted at			600 feet
Missiles thrown, up to			In river, no record
Glass broken, up to			1 mile

FONTANET, INDIANA

Chart No. 44

There was an explosion at the black powder works, at Fontanet, Indiana, on January 29th, 1907, at 3.30 P. M.

The explosion originated in the press mill, and involved a wheel mill 200 feet away.

The foreman of the powder line had been in the press mill five minutes before the explosion, and when he left the building one press was full of powder and under pressure, and the two men in the building were stripping the powder cake out of a second press. There were five full pressings of powder on cars, and four charges of wheel cake on the floor.

A flying ember dropped on the wheel mill and caused the explosion there. No one was in this building at the time.

In all, the explosion involved about 25,000 pounds of black powder.

The two men in the press mill were instantly killed. No one else was injured.

The immediate cause of the explosion was unknown, but the men on the powder line were inexperienced hands, who could not be taught to take proper precautions, so that the explosion may have been due to their carelessness.

Regarding the effect of the explosion on other buildings on the plant; two corning mills were slightly damaged, and also the glaze mill. The shed between the corning mill and glaze mill collapsed with eight cars of grain powder standing under it. The roof of the power house was slightly damaged.

Outside the plant, the damage to property in Fontanet consisted of broken windows and doors. The area of structural damage was within 600 feet. Glass was broken at 1050 feet.

Missiles were thrown 375 feet. The force of the blow went to the north-east, and debris of any size was thrown in that direction, with the exception of a few pieces of wood and plates which were scattered to the south and west.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Plant buildings	No barrier	Slight damage	600
Area of structural damage			600 feet
Charted at			300 feet
Missiles thrown, up to			375 feet
Glass broken, up to			1050 feet

COUNCIL BLUFFS, IOWA

Chart No. 35

There was an explosion of a carload of dynamite in the C. R. I. and P. Railroad freight yard, Council Bluffs, Iowa, on September 26th, 1881, between 4 and 5 P. M.

The car of dynamite was reported on fire, and upon investigation, smoke was seen coming out of the top of the car near the center. A pay car standing nearby was taken to the lower end of the yard out of the way, and an engine with a string of cars ahead of it pushed the burning car to a water tank. A man had climbed up on the tank and pulled down the water spout, but before the water could be turned on the roof of the car raised and flames burst forth. The man jumped, and had barely passed through the round house when the explosion of the 25,000 pounds of dynamite occurred.

When the scene was examined after the explosion, the powder car, the box car ahead of it, the water tank and a pile of timbers nearby had disappeared, and only a pair of railroad trucks remained.

The round house was knocked down, and a two-story brick car shop which stood about 50 feet south from the explosion was so completely demolished that not a brick was found.

Sixty freight cars were wrecked, and the freight house to the north was blown over.

A crater was formed 15 feet deep and 90 feet across.

The cause of the fire was unknown, but the car may have caught on fire from a hot box, or from a spark from the engine.

Much structural damage was reported to have been done to railroad buildings and houses within a radius of a quarter of a mile. Much of the damage done was by vacuum; windows were drawn out instead of blown in. In the Union Pacific transfer passenger station, almost a mile away, the windows on the side nearest the explosion were all shattered. Nearly all the windows in the business portion of the city over a mile away, were broken.

There was no one killed or seriously injured, though two people were reported slightly hurt. Undoubtedly there would have been more casualties if nearly everyone from the yard and vicinity had not gone up to attend the Garfield funeral services in another part of town.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Railroad buildings and houses	No barrier	Much structural damage	1320

SUMMARY—Continued

Area of structural damage.....	1320 feet
Charted at.....	660 feet
Missiles thrown, up to.....	No record
Glass broken, up to.....	1½ mile

PINOLE, CALIFORNIA

Chart No. 57

On February 20, 1908, at 3:50 P. M., there was a serious explosion on the high explosives works at Pinole, California.

There were two distinct explosions, and from eye witnesses it appeared that the dynamite in a Quinan packing house was the first to explode, followed immediately afterwards by an explosion of loose powder in boxes on tram cars being transported from a mixing house to a Hall machine cartridging house.

When the first explosion occurred, the tram train composed of a compressed air engine and three cars was at a point opposite and about 400 ft. from the Quinan packing house, in the open, but protected to some extent by the crib barricade of the Quinan packing house.

The Quinan packing house was completely demolished. Only portions of the barricades, which were in front and at one end of the building, remained.

The cars of the tram train were demolished and the engine severely damaged.

There were eight packing machines in the Quinan packing house used for packing or cartridging dynamite and all were reported in good condition prior to the explosion. The crew of the house consisted of a white foreman and 23 Chinamen, and as far as known the process of packing the powder was being carried on at the time of the explosion.

The explosion killed the foreman and his remains were found about 150 ft. from the Quinan house in such condition as to indicate he was outside of the building and was probably killed by shock. The 23 Chinamen were instantly killed and only in two instances was identification possible.

The crew of the powder train, consisting of engineer and two brakemen, were killed by the explosion of the powder on the cars.

Two men working on the tram tracks, over which the cars of powder had passed, were injured, one severely. Considering that the men were 150 ft. from the explosion of over three tons of dynamite, it is remarkable that they were not killed.

Six other employees suffered from lacerations, bruises and shock.

The following quantities of explosives were involved in the two explosions:

In the Quinan Packing House—26,362 lbs. dynamite.

On the Tram Cars—6,400 lbs. dynamite.

Between 118 ft. and 1250 ft. of the Quinan Packing House there were 20 factory buildings, all frame construction. A box storehouse at 118 ft. was demolished; between 375 ft. and 700 ft. a number of buildings were wrecked, and up to 1150 ft. buildings suffered severe damage. Beyond this distance, and up to 2500 ft. there were 10 or 12 buildings which were only slightly damaged.

Since about 80% of the quantity of powder that exploded was in the Quinan Packing House, a partly barricaded building, it was justified to consider that this was the quantity against which the damage should be measured, and that the damage from the powder on the cars did not extend beyond that caused by the explosion in the Quinan Packing House.

Most of the debris thrown were pieces of tramway rail, some of which were picked up 1500 ft. away from the scene of an explosion.

A large number of windows were broken in the town of Pinole and for miles around.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Plant Buildings	Barricaded	Roof damaged	1150
Area of structural damage.....			1150 feet
Charted at.....			1150 feet
Missiles thrown, up to.....			1500 feet
Glass broken, up to.....			Several miles

CARABANCHEL, SPAIN

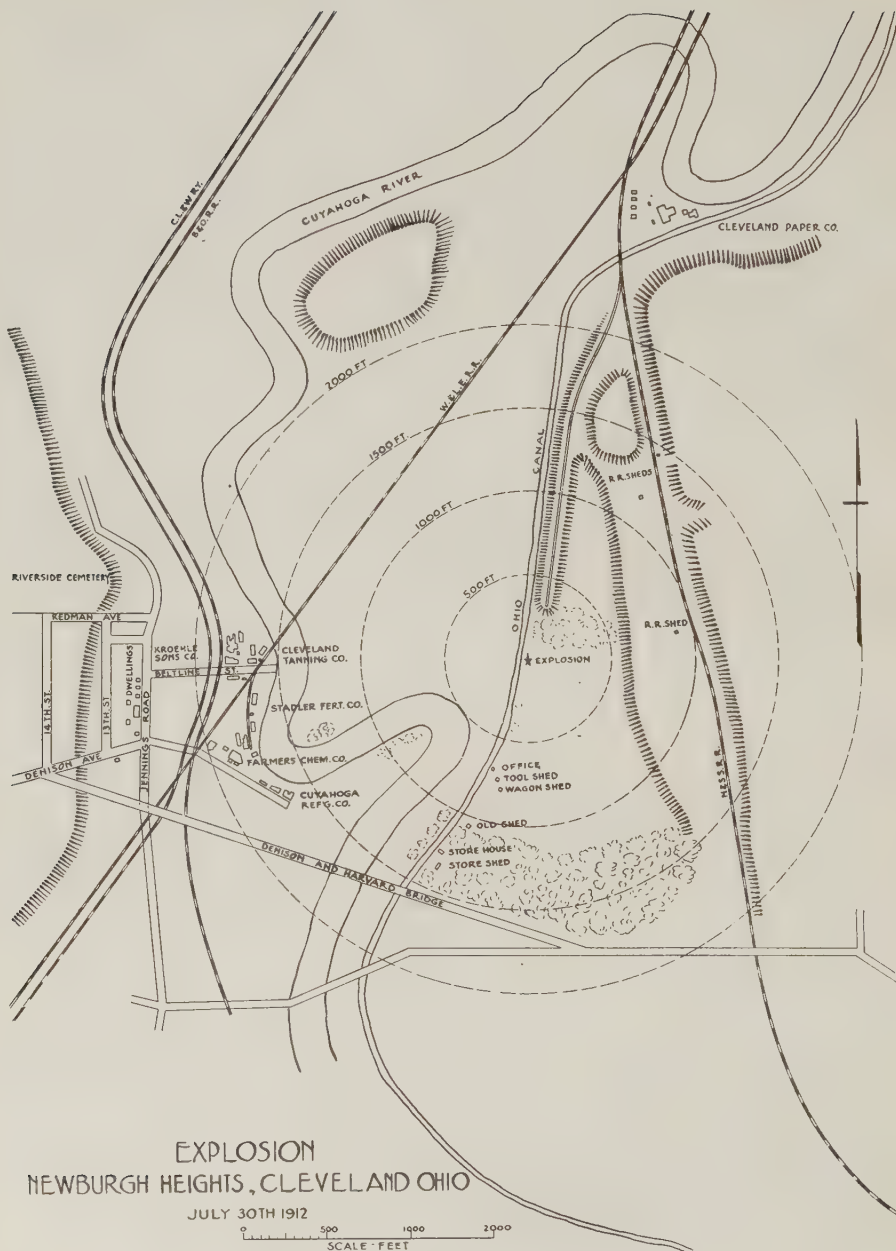
Chart No. 21

There was an explosion at Carabanchel, near Madrid, Spain, on June 26th, 1902, in a small powder magazine. There is no definite data as to the protection around the building.

The quantity of explosives stored there at the time amounted to 26,686 pounds, about half of which was nitro-compound and the remainder gunpowder. Probably not more than two-thirds of the quantity exploded.

Spontaneous decomposition of a part of the nitro-compound containing nitroglycerin is thought to have been the cause of the explosion.

The laboratory, 162 feet away, was completely wrecked, although the



walls were of brick and two feet thick. The roof collapsed but some dynamite cartridges in the building were not detonated.

Two old houses, 660 feet away, were so badly shaken that it was deemed advisable to pull them down. The door of a powder magazine at 760 feet was torn off, but no further damage was done. Doors and windows were broken in warehouses at a distance of 1968 feet, and window panes were broken at a distance of $3\frac{3}{4}$ miles.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Two old houses	Not known	Badly shaken	660
Area of structural damage			660 feet
Charted			660 feet
Glass broken, up to			$3\frac{3}{4}$ miles
Missiles thrown, up to			No record

NEWBURGH HEIGHTS, CLEVELAND, OHIO

Chart No. 164

On the morning of July 30th, 1912, at 7.40 o'clock, the contents of two magazines exploded at Newburgh Heights, Cleveland, Ohio. The magazines were on the Ohio Canal Towpath between Denison Avenue and the Wheeling and Lake Erie Railroad.

The property on which the magazines stood was formerly a black powder plant, which had been partly dismantled and abandoned. The magazines were used for storage of explosives for local delivery and shipments. They were constructed of brick on stone foundations with slate roofs and iron doors, the black powder magazine being about 20 feet north of the dynamite magazine.

There were no artificial barricades around these magazines. To the north, however, the end of an embankment, about 75 feet broad and 30 feet high, was within about 300 feet of the magazines, and there was also about half an acre of fair-sized willow trees which covered the area between the embankment and the magazines.

To the east the ground was practically level for about 650 feet, then came a rise of about 50 feet high and 350 feet wide, upon which were located the N. and S. S. Railroad and a number of sidings. Beyond this level, and about 1,000 feet from the magazines, a bluff arose abruptly 50 or 60 feet, from the top of which the country for a mile was open and level.

To the south for about 1,000 feet the ground was level and open, from which point to the Denison-Harvard Bridge there was a heavy growth of

timber. The Denison-Harvard Bridge extended across the valley of the Cuyahoga River 1,500 to 1,600 feet south of the magazine, the bridge being about half a mile long and about 75 feet high.

To the west across the canal there was a flat piece of country for more than half a mile, traversed by the Cuyahoga River. On the far side of this lowland, the ground rose abruptly for 50 or 60 feet, and on the heights above there was a closely built section of Cleveland.

At the time of the accident the following explosives were contained in the magazines:

Dynamite magazine	18,000 pounds
Black powder magazine	8,750 pounds
Total	26,750 pounds

There was nothing left of the magazines after the explosion. At the site of the dynamite magazine there was a hole about 10 feet deep and 60 feet in diameter. The black powder, however, made no excavation. In the immediate vicinity, trees were uprooted and thrown considerable distances. The willows to the north of the magazines were blown down, between the magazines and the end of the railroad embankment, for a width of about 75 feet; 25 feet further back the trees were in very fair condition under the circumstances. A field of corn to the east, between the magazine and the embankment was cut off close to the ground and had entirely disappeared.

The nearest structures to the scene of the explosion were the buildings which were formerly part of the abandoned black powder mill, the damage resulting as follows:

The office, a small frame one-story building, 15 by 18 feet, 700 feet south of the explosion, had the side towards the magazine injured, 2 x 3 inch studding broken, siding torn loose and split. The inside partition was pulled out, rafters broken, and roof smashed in. Windows and doors were ripped out. One end of the building was plastered with brick dust from the explosion, and there were a number of holes made by missiles.

An old frame tool shed, 18 x 20 feet, 730 feet south of the explosion, was practically wrecked. The side of the building facing the explosion was shattered, rafters broken and sidings torn off, and roof collapsed.

The old wagon shed, a ramshackle frame building 20 x 30 feet in size, 775 feet south of the explosion, had studding broken and sidings torn off, on the side towards the explosion, the rafters broken and roof sagging.

An old shed, a flimsy frame construction 25 x 25 feet, 1050 feet south of the explosion, had the end towards the explosion smashed in, two 2 x 4 inch rafters broken, and roof opened at peak. Missiles, consisting of brick and

pieces of foundations, were scattered over the floor of this building.

The keg storehouse, 1350 feet south of the explosion, was uninjured.

An old railroad shed, 900 feet east of the explosion, 9 x 10 feet in size, built of frame construction, had a few studdings and nailing strips split, the side away from the explosion shoved out of line about 3 inches and window glass broken, glass being thrown inside of building.

A second railroad shed, 1400 feet from the explosion, sustained no damage.

A third shed, 1200 feet from the explosion, which was a low frame building used to store the section gang's tools, had five $2\frac{1}{2}$ x 4 inch rafters broken, and the roof let down about six inches, one window ripped out, glass in another window broken and thrown inside of building.

The plant of a tanning company, 1600 feet west of the explosion, consisted of three large buildings, two of which were of frame construction and one of brick. There were also some small buildings. The brick building along the railroad nearest to the bridge over the Cuyahoga River had all the windows on one side ripped out, and the shafting and some of the machinery moved out of place. The other buildings of this plant were all frame, and the only damage consisted of glass breakage.

A small frame two-story house, 1700 feet west of the explosion, had glass broken and plaster down.

The buildings of a fertilizer company, 1700 feet west of the explosion were grouped along the railroad siding, and in some instances suffered serious structural damage.

The packing and shipping house, a large frame building 180 x 100 feet, practically new, had the side towards the explosion pulled out four or five feet from the foundations for about 50 feet, studdings 2 x 4 inches x 20 feet were split, and braces 6 x 6 inches between the wall and the inside partition had dropped out of place. Window frames were ripped out.

The rendering house, a three-story brick building, had windows broken.

Two warehouses, part brick construction and part frame, had a wall of the frame portion bulged three or four feet, and at another point a brick wall was cracked three or four feet from the top and out of plumb two or three inches, the roof raised and the rafters separated from the side supports.

The grinding house, a frame building, had the side towards the explosion injured, three 6 x 6 inch studdings broken and sideboards pulled loose.

A chemical plant, 2000 feet west of the explosion, consisting of a group of low frame and brick buildings, suffered no damage except glass breakage.

A refining plant, 1700 feet west of the explosion, consisted of a line of

two-story frame buildings at the end of Denison Avenue. The principal damage was the breakage of window frames and glass.

A number of dwellings along Jennings Road to the west of the explosion suffered no damage other than broken glass and a little plaster knocked down here and there.

The paper company's building, 2800 feet to the north of the magazines and protected by the natural features of the ground, had a few boards in the light shaft broken and some glass breakage.

The area of missiles was about 1,000 feet. The greatest number were thrown to the north and west of the magazines. To the west, the ground between the canal and the W. & L. E. Railroad for about 700 to 800 feet was literally covered with pieces of brick, whole bricks, large stones from the foundations, (the majority of which were blackened and apparently came from the black powder magazine) and pieces of trees. To the north, the willows and the railroad embankment stopped a large amount of the debris.

To the east and south for about 700 or 800 feet the missiles were few, but the ground and trees were practically covered with brick dust, so much so that in walking through the brush, weeds, etc., clothing would be perceptibly reddened. Beyond 700 feet south and up to 1000 feet, pieces of brick and foundation had fallen in considerable quantities. Only a comparatively few pieces of keg metal were found.

The greatest distance to which missiles were thrown was about 1800 feet.

A number of persons were reported by the newspapers to be injured. The only instance in which definite information could be obtained was the case of a woman and a boy who were with a horse and wagon across the canal, about 150 feet from the magazines. The boy was struck on the head by a missile, but the woman escaped unhurt. The horse was killed by being struck on the neck by a missile. Evidently the woman and boy were protected by the horse and wagon.

The breakage of glass was less than would have been expected from the amount of explosives involved. Only in the valley to the west of the magazines was the breakage general; beyond this it was more or less scattered over an area extending for about a mile. A few instances occurred up to three-and-a-half miles.

The windows of a caboose on an ore train running along the N. & S. S. R. R. about 1000 feet from the explosion were broken, but a brakeman sitting in the caboose was unhurt.

There did not seem to be any explanation for the explosion. The magazines were last visited the day before the accident. The theory was advanced that the trouble originated in the dynamite magazine, the explosion of the black powder following so closely as to be simultaneous.

This was not borne out, however, by the fact that pieces of keg metal were found perforated or dented by missiles, which would seem to indicate that the black powder exploded first, and while the keg metal was in the air it was struck by debris from the dynamite magazine.

The accompanying map of the country in the vicinity of the magazines show the location of the explosion and various buildings in the neighborhood.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Packing & shipping house	None	Side pulled out, studing split	1700
Area of structural damage			1700 feet
Charted			850 feet
Missiles thrown, up to			1800 feet
Glass broken, up to			3½ miles

STOWMARKET, ENGLAND

Chart No. 92

On August 11th, 1871, an explosion of 13½ tons, or 27,000 pounds, of guncotton occurred at Stowmarket, England.

The explosion took place almost simultaneously in three magazines, which were unbarricaded. The contents of one of the magazines exploded, and the contents of the other two were exploded by projectiles from the first, or by the collapse of the buildings, and blows caused thereby.

The cause was thought to be decomposition, due to the acidity of the nitro-cotton.

The buildings of the factory were almost completely destroyed. Buildings situated from 60 to 150 feet from the magazines were entirely demolished. At 900 to 1200 feet, cottages of light construction were almost destroyed. As a general rule, serious damage was limited to a range of from 1350 to 1500 feet, and between one quarter and three quarters of a mile, some slight material damage was done in the way of weak walls broken, the church mullions divided and some gable ends blown in. Window sash and frames were broken up to a distance of about one mile.

The noise of the explosion was heard for a distance of 30 miles, and the shock was felt for a distance of about 7 miles. At 5 miles, an iron bar which secured a door was broken. There was no record kept of projected debris, but glass was broken at a distance of 4 miles.

Some of the buildings were set on fire by the explosion, and a second small explosion occurred about three-quarters of an hour after the first, adding to the loss of life but not materially to the damage.

There is no record of the number of lives lost in this explosion.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Factory buildings	No barricade	Serious damage up to	1500
Area of structural damage			1500 feet
Charted at			750 feet
Missiles thrown, up to			No record
Glass broken, up to			4 miles

REDDICK, ILLINOIS

Chart No. 80

An explosion occurred at Reddick, Illinois, at about 5 o'clock on the afternoon of June 4th, 1907, when a freight car containing 30,000 pounds of dynamite caught fire.

The freight train of the Chicago, Indiana and Southern Railroad composed of two engines and fifty-five cars was traveling west near Reddick. A hot box developed on one of the oil cars of this train, as was noticed by a farmer living a mile and a half east of the Wabash Railway crossing, and when the oil car was 1267 feet from the crossing, the axle broke or burnt off, letting it down on the ties. The train broke in two, and the engine and the cars attached ran nearly to the C. I. and S. S. depot before stopping.

The oil cars which were derailed immediately took fire, fanned by a light wind blowing south east. The fire burnt for ten minutes, allowing time for about 50 or 100 people to collect, the black dense smoke from the burning oil enveloping the cars behind so that none of the onlookers saw the sign HIGH EXPLOSIVES on the side of the dynamite car. Everyone in the town was on his way to the fire when the explosion occurred, ploughing a hole 167 feet long, 70 feet wide, and 20 feet deep.

Three men were killed outright. One man, the village barber, was in the act of crawling under a barbed wire fence, 200 feet south of the railroad tracks, when he was struck in the neck by a piece of flying pipe which almost severed his head from his body, killing him instantly. The other two men who were killed were stealing a ride on the car containing iron pipe. They were blown to pieces. A fourth man stealing a ride in the pipe car was badly burned and bruised, and did not live long.

Nineteen men were injured, more or less severely. Some boys had gone as close to the dynamite car as 35 feet, but as they were protected by the wrecked boilers, they were only stunned for about half an hour.

Sixteen cars were destroyed, the balance being saved by getting an engine from Kankakee, 20 miles away, and pulling them east from the fire.

The nature of the ground in the locality was flat and bare, and the town was practically unprotected. The town of Reddick was 67 miles south of Chicago, a very small place with about 500 people, few dwellings and few stores. The extent of damage to the town was light. Of the 18 plate glass windows in town, 12 were broken.

A farmer living a mile and a half from town had seven windows broken on the west side of his house. He picked up two pieces of iron weighing about 13 pounds near his house, and pieces of charred wood.

Smith's ice house, 2800 feet from the explosion to the south, was struck by a piece of iron weighing $16\frac{1}{2}$ pounds, which broke through 5 one-inch planks, a foot and a half of sawdust, through two cases of beer, and then made quite a dent in the floor.

A farmer grading a road about a mile east of the wreck, was thrown to the ground, and his four horses were also thrown down.

The towerman at the crossing had a narrow escape. He was standing on the tower steps watching the oil cars burn, when the explosion took place, lifting the heavy tower and placing it 105 feet southeast in an oat field. The man was thrown 200 feet in the same direction, but escaped with only bruises.

The depot, 1300 feet west of the Wabash tracks, had window lights broken and a lamp blown off the wall. The grain elevator across from the depot had a dent in the roof on the east, from concussion.

The wind was blowing very lightly and had very little effect on the heavy debris thrown into the air, but it managed to carry plenty of the light stuff that was thrown high as far as a mile and a half southeast. The town was well strewn with pieces of iron, wood, etc.

Owing to the scarcity of buildings, in the vicinity of the explosion, this is not considered a fair case from which to measure damage area.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
R. R. depot	No barrier	Few windows broken	1300
Grain elevator		Roof damaged	1300

SUMMARY—Continued

Area of structural damage.....	1300 feet
Charted at.....	650 feet
Missiles thrown, up to.....	2800 feet
Glass broken, up to.....	3 miles

FORT LYONS, WASHINGTON, D. C.

Chart No. 50

On June 9th, 1863, at 2.00 P. M., a powder magazine exploded at Fort Lyons, Washington, D. C.

While soldiers were engaged in examining artillery ammunition at the open door of the north magazine, one shell exploded, immediately after a few others, then the whole contents of the magazine.

Between 20 and 30 men were killed, and as many others severely wounded.

The floor of the magazine in which the explosion occurred was 9 feet below the parade. The powder space was 64 feet by 7 feet by 7 feet, covered by heavy logs and 8 feet of earth. The total amount of explosives was 32,000 pounds of black powder.

A crater was formed 45 feet in diameter. The parapet of the fort, although within 80 feet, and rising several feet above the terreplain, was hardly injured. Wooden buildings near the magazine were destroyed, but a bomb-proof which held most of the garrison at the time, escaped uninjured.

A house 1050 feet distant had its windows blown in and its doors blown out. The walls were started in one place more than an inch, and the whole house was settled unevenly on its foundations.

Several persons were lifted up and thrown to considerable distances.

Loaded shell were thrown to various distances, up to 7500 feet.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
House	Underground barricaded	Windows and doors blown in, and foundation damaged	1050
Area of structural damage.....			1050 feet
Charted.....			1050 feet
Glass broken, up to.....			No record
Missiles thrown, up to.....			7500 feet

COOLGARDIE, AUSTRALIA

Chart No. 34

The explosion of the contents of a powder magazine early on the morning of May 19th, 1904, caused considerable excitement at Coolgardie, Australia.

The stock in the magazine at the time of the explosion was about 17 tons, or 34,000 pounds of nitro-glycerin explosive.

As to the cause of the accident, evidence was produced at the inquiry to the effect that samples drawn recently from the magazine had been examined, and the heat tests had shown considerable falling off in the stability of portions of the stock. Samples had been taken in January, and in consequence of a bad heat test the Chief Inspector of Explosives in Western Australia ordered further samples taken. This was done in February, and further deterioration was shown by a reduction of the time in which the samples stood the heat test. In March instructions were issued to get rid of the stock at once, but the instructions had not been carried out.

The nearest building was another small magazine, about 300 feet away from the site of the explosion. This was not damaged, but a condensing plant, 450 feet away, was considerably damaged, and a magazine at 600 feet was unroofed and the contents of the powder cases scattered about.

The damage done in the town of Coolgardie, about half a mile away, was principally confined to broken glass, though in some cases doors were blown in. No instance of structural damage was reported.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Magazine	In doubt	Unroofed, and contents scattered	600
Area of structural damage			600 feet
Charted			600 feet
Missiles thrown, up to			No record
Glass broken, up to			1 mile

FORDE, GERMANY

Chart No. 49

On the 14th of December a serious accident took place at the Forde Dynamite Factory, Forde, Germany, by which three men were killed, and one overseer, and sixteen other workmen were more or less seriously injured.

The explosion originated in a cartridge hut, and was communicated by projected debris to the dynamite magazine and the collodion-cotton stove.

Of the three men killed, one was found in the cartridge hut sitting at the worktable and still holding a cartridge in his hand. The force of the explosion, or the fall of the wall of the hut, had shattered the left side of his head and broken his neck. A second man at work in the same hut was practically blown to pieces. The third man was thrown over the wall of the collodion-cotton stove in which he was apparently at work, and beyond slight burns had received no external injuries.

One of the injured, a cartridge maker, was very curiously affected. He was uninjured externally, but had evidently suffered concussion of the brain, the result being that all recollection of the occurrence had completely gone. Even after two and a half weeks, he could not remember anything that had happened on the day of the accident; but he then took a sudden turn for the better and in the course of a week his mental condition became entirely normal.

The cause of the accident has not been ascertained. The unfortunate man who was blown to pieces, and who was regarded as being the originator of the explosion, was a thoroughly steady and reliable man, and on the very day of the accident his appearance and generally active demeanor had been specially noticed by the officials.

The majority of the injured were cartridge makers in adjacent huts, and they were able to crawl out from under the debris without assistance. The first impression was that only one explosion had taken place, that is, in the cartridge hut, and it was not until the next day that the stove man's body was found.

In the cartridge hut were about 33 pounds of gelatin dynamite, and in the stove about 17,000 pounds of collodion-cotton. In the magazine there were 635 cases, presumably of 55 pounds each, making a total of 34,950 pounds of gelatin dynamite, and 17,000 pounds of collodion-cotton.

In proportion to this large amount of explosive, the damage was limited to a very small area. Two workmen loading a wagon in the space between the cartridge huts, the packing house and the stove, at a distance of about 360 feet from the magazine, were thrown down by the shock, as was also the man in charge of a tram-load of explosive. This tram-wagon, containing 110 pounds of gelatin dynamite, was ignited by the burning debris of the stove, and quietly burned away.

As regards material damage, the area of violent effects seems to have been limited to a radius of 164 feet from the magazine, and all buildings within this zone, such as the cartridge huts and the packing house, were entirely demolished, all the packers and cartridge men being more or less severely wounded. In many instances the design of the wire wove material from the windows had been actually imprinted on the men's bodies.

The corrugated iron fence, seven feet high, which surrounded the fac-

tory, was destroyed for a length of 1148 feet. Some of the sheets were projected to a distance of 164 feet, and remained hanging in the trees.

The passages to the cartridge huts were partly erected with bricks made from slag, with concrete vaulting 12 inches in thickness. The concrete vaulting had not proved efficient, nor had the bricks made from slag, whereas three passages constructed with either ordinary stones or bricks, and which had a vaulting of bricks, all proved absolutely serviceable.

The zone of secondary effect extended to the mixing house, about 495 feet away, and the buildings within this radius were so seriously damaged as to require rebuilding, most of the frame posts and roofing timbers being sprung and the walls bulged.

Beyond 495 feet, the damage was considerably less. Tiles were in some cases removed, doors and windows broken, and here and there a roofing timber sprung, but the necessary repairs were effected in a very few days.

In the surrounding neighborhood, the damage extended to rather less than two miles, but the breakages were of a trifling nature. In Bonsel, a distance of 1650 feet, the worst loss was experienced, whereas in Forde-Grevenbruck—not 1200 feet distant—only window frames were broken.

About 5,000 pounds of gelatin dynamite were buried in the cartridge huts and packing house, and the cartridge machines, all of which were seriously damaged, were found still full of explosive.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Factory buildings	Barrier	Seriously damaged and required rebuilding.	495
Area of structural damage.....			495 feet
Charted.....			495 feet
Missiles thrown.....			No record
Glass broken.....			2 miles

CONNABLE, ALABAMA

Chart No. 33

At midnight, July 25th, 1907, there was an explosion at the black powder plant at Connable, Alabama.

The explosion originated in the glaze mill and involved the corning mill. The glaze mill was screened by hills and timber, and the corning mill was protected by a concrete barricade. Both buildings were of frame construction.

There were two explosions, the second following immediately after the first. From the evidence, it appeared that the glaze mill was the first to explode, and the second must have been from the corning mill, rendered a little more severe on account of a part of a car of cut grain left in the mill over night.

About 37,500 pounds of black powder exploded, practically all of which was in the glaze mill.

No cause for the accident could be assigned. The evidence indicated that the mill was shut down, which was corroborated by the fact that the clutch between the motor house and the mill was found in its place intact and positively disengaged. The position of the bodies of the two men killed indicated most conclusively that they were both on the upper floor of the glaze mill when the accident happened, and were therefore probably re-charging the glaze barrels from the green grain cars on the upper floor.

Well defined boundaries of four distinct holes under two of the car sheds, in front of the glaze mill indicated that four carloads of finished grain had been run out from beneath the glaze barrel from which the powder had been dumped. That two carloads of finished grain had been dumped and left standing underneath the barrel, was evidenced quite conclusively by the fact that the cylinder of the barrel remained intact, and it would not have been projected the distance it was unless propelled from beneath.

The glaze mill was totally destroyed, as was also the corning mill, 400 feet distant; this latter building by internal explosion.

The keg paint house, 320 feet away, was quite badly wrenched, some studding and rafters split and broken, and a part of the siding and roof torn off.

The office and keg shop, 600 feet away, were damaged. The walls facing the point of the explosion were practically torn out and two dormer windows badly damaged.

The wash house, 400 feet away, had all windows broken, and the frame walls facing the explosion slightly pulled out of place.

The magazines, 600 to 800 feet away, had doors pulled out of place, but no other damage.

The power house, about 600 feet away, had the roof trusses damaged. The rear side wall had to be rebuilt from a point three feet below the top, for more than half its length. Most of the sash in this building were broken.

Quite a number of missiles were thrown by the explosion in the glaze mill. The following will give an idea of the missile zone:

Cylinder (damaged).....	195 feet
Piece of shell 3 feet square.....	881 feet
Cylinder (unbroken).....	1018 feet
Piece of cylinder head.....	1720 feet
Inside jacket of cylinder.....	3500 feet

The body of one of the workmen was thrown 710 feet to the northeast, and the other 636 feet southeast. In order to clear the timber over which the bodies were thrown, they must have risen to a height of 150 feet to 200 feet in the air.

The glass breakage was confined to a zone of about half a mile.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Keg shop and office	Hills and timber	Side torn out.	600
Area of structural damage			600 feet
Charted at			600 feet
Missiles thrown, up to			3500 feet
Glass broken, up to			½ mile

KEEKEN, GERMANY

Chart No. 110

On March 19th, 1895, at 6.15 P. M. there was an explosion of dynamite which was being loaded on a barge on the Vossegatt at Keeken, near Schurpoll, Germany.

From the 23rd to the 26th of January, 3,004 cases of guhrdynamite and 4,900 cases of blasting gelatin were loaded at Porz, on the Rhine above Cologne. This shipment was made in execution of a large monthly order given by the government of the Transvaal Republic, and was to be forwarded via Antwerp by the steamer "Chemnitz" to Port Elizabeth.

Between Porz and Ensen, about two hours above Cologne were the three landing stages belonging to the United Explosives Companies. At this point the river bank was very high, and fell abruptly toward the Rhine. The loading stages had a strong incline down the bank. Here the dynamite was loaded on the Rhine barges by means of wheelbarrows, each loaded with seven cases, and provided with brakes on account of the steep incline. The Porz bargemen had done this work for twenty years, and had always done it without hitch or disturbance.

According to the Dutch regulations, the whole shipment, which in this case was made in three barges, could not be transported directly from Porz to the transport ship, but had to be transferred at the Dutch frontier near Lubith into seven barges. The regulations since the very beginning of dynamite transportation through Holland, required a single barge to contain not more than 66,000 pounds of explosives. Although every barge added to the tug increases the danger of collision, and although suitably

arranged large barges are undoubtedly safer than small wooden or iron sailing barges, the regulation was unchanged for 25 years.

Seven barges received the explosives at the Dutch frontier, in the following quantities:

"Veer Gebroeders"—1500 cases guhrdynamite, 600 cases blasting gelatin.

"De Duif"—900 cases blasting gelatin.

"Elizabeth"—1100 cases blasting gelatin.

"Gesina"—800 cases blasting gelatin.

"De Hoop I"—1500 cases blasting gelatin.

"Marie Odelia"—1500 cases guhrdynamite.

"De Hoop II"—44 cases guhrdynamite.

These latter 44 cases, destined for the Royal Netherland War Office, were forwarded before the explosion, and therefore need not be taken into account.

While the explosives were being transferred from the three barges to the seven, which was done on the 29th of January, a severe freeze suddenly set in, causing in a very short time the formation of considerable quantities of ice on the Rhine. While the barges were at Porz, the weather was mild, and it was not foreseen that ice would appear so rapidly. The float ice increased on the morning of the 29th to such an extent that the barges could no longer hold their own. The distress flag was hoisted and the barges towed into the Vossegatt near Keeken, opposite Lubith, for safety. In the hope that the weather would be milder, the escort remained in readiness on the 30th of January, but the cold continued, and the tugs brought the barges further into the Vossegatt, where they anchored.

Those in charge of the barges at once notified the authorities, and the possibility of danger through ice in case of floods was discussed with the Explosive Companies. The authorities considered it inadmissible to leave the barges where they were. A proposal made by the explosive companies to place the contents of the barges in an iron lighter in the Spoy Canal, was rejected by the authorities on account of the vicinity of villages. They later reconsidered the proposal, but its execution was then impossible, the cold having increased to such a great extent. Inhabitants of the district stated that in case of floods, a great deal of float ice might be expected to appear in the Old Rhine, and the authorities then ordered that the dynamite was to be removed as soon as the ice became blocked near Keeken.

A suitable site had to be found in the vicinity. Schurpoll at Salmorth in the district of Griethausen was chosen as the most suitable, 360 feet from the place the barges were then lying.

On the 17th of February the ice in the Rhine came to a stoppage, and

arrangements were made at once to land the goods. Representatives of the explosive companies, government inspectors and local police were present.

A wooden stage was constructed 30 feet broad, 63 feet long, and two feet high, made of strong beams and planks, having all around fascines to prevent the water coming in in case of floods. The roads from the Vossegatt to the storing place was chiefly over meadows, and was levelled by means of straw and manure. The dynamite was brought from the barges to this place of storage, 20 carts being used for the purpose. Each trip took about three-quarters of an hour. This difficult work was completed on February 24th. The dynamite was covered with waterproof tarpaulins to protect it from damp and rain. Police and civilian watchmen were placed on guard day and night, changing every four hours.

When the ice disappeared, the authorities ordered the reloading of the dynamite on the 18th of March. Only experienced men were to be employed. The men from Porz took the whole loading in hand in the same way as they had done so often without accident. They brought their wheelbarrows with them, on which they placed 7 cases, and brought them down as they were in the habit of doing. The connection between the land and the barges was made by means of planks laid across trestles, and when the cases came aboard on the wheelbarrows they were handed over to the bargemen standing by a chute. This chute consisted of two planks, sloping off the hatch and went down to the bottom of the barge, about 6 feet. In this way the bargemen and the workmen worked together.

The dynamite storage place about 360 feet from the barges was connected with them by means of two rows of planks, one serving for the transportation of the loaded barrow, the other for bringing back the empty ones to the store.

In the course of the 19th of March, the "Maria Odelia", an iron barge, and the "Veer Gebroeders", built of wood, were each laden with 1500 cases, and anchored about 60 feet upstream to make room for the wooden barge "Elizabeth."

When this barge had been loaded with 502 cases of guhrdynamite and 432 cases of blasting gelatin, a dreadful explosion took place. This was at 6.15 P. M. The barge, together with its entire contents, was blown into the air. At the moment of explosion, a man was standing with his loaded barrow on board the "Elizabeth." Two of the wheelbarrows loaded with 7 cases of guhrdynamite were 66 and 85 feet away respectively, and this dynamite also exploded.

The subsequent investigation showed that 19,038 pounds of blasting gelatin, and 22,752 pounds of guhrdynamite exploded, making a total of about 41,800 pounds.

The barges "Maria Odelia" and "Veer Gebroeders", which were 60

feet away from the "Elizabeth", sustained considerable damage, but their contents did not explode.

The empty barge "De Hoop", 60 feet away, burst into flames immediately after the explosion, burned, and sank.

The cause of the explosion can never be determined with any degree of certainty. Both the explosives were nitro-glycerin compounds. In the case of the blasting gelatin the fluid nitroglycerin is converted into a gummy elastic mass by the addition of 8% of collodion cotton, and in the case of the guhrdynamite, the nitroglycerin is mechanically mixed in the proportion of three parts to one of Kiesselguhr, and thereby converted into a plastic mass.

Two chemists tested the remaining dynamite and blasting gelatin after the explosion, and each reported that the explosives had the required stability.

It was suggested that the frozen condition of the explosives might have been the cause of the explosion. By far the largest portion of the explosives must have been frozen at the time of reloading. If on the one hand it is shown that frozen dynamite is less sensitive than non frozen, it cannot be denied that in certain circumstances frozen dynamite will explode more readily.

It might have been that one of the wheelbarrows loaded with dynamite and provided with an iron brake, dropped into the hold of the barge and caused the explosion.

All the men on board the barge "Elizabeth" were killed, a total of seven men. The captains of the barges "Veer Gebroeders" and "Maria Odelia", three workmen with wheelbarrows, and also two persons on barges in the vicinity were killed, making 14 fatalities in all; besides several others injured, three seriously.

Apart from the lamentable loss of human life, the damage done by the explosion to property in the vicinity was also most considerable.

The loaded barges, which were moored at a distance of only 60 and 90 feet respectively, were not involved, and this is attributable to the fact that the water surrounding the barges acted as an elastic cushion in lessening the shock.

A diver searched the river bed at the place of the explosion, and reported that it was in natural condition with the exception of a hole about 60 feet long, 60 feet wide, and 6 feet deep. The burnt barge was lying at the bottom of the river, but no remains of dynamite cases were to be found.

A small amount of the debris from the "Elizabeth" was scattered on the shore at a circumference of about 4500 feet.

In the case of an explosion, a distinction has to be made between two different effects; the direct and the indirect. The former is caused by the gases produced by the explosion, being expelled with immense velocity, and by the atmosphere which is carried along with them; the indirect effect is caused by the volumes of air forced towards the center of the explosion. The gases forced upwards with extraordinary speed in the shape of a large cone, act like a gigantic suction-pump on the neighboring atmospheric strata, which are sucked with great vehemence to the center of the explosion. From this it follows that the direct effect extends only to comparatively short distances but with great vehemence, while the indirect effect asserts itself at greater distances, but less forcibly.

The damage done to the barges was as follows:

The decks of the two loaded barges "Veer Gebroeders", built of wood, and "Maria Odelia", built of iron, lying at a distance of 60 to 90 feet from the "Elizabeth" were forced out. The "Veer Gebroeders" sprung a leak, admitting water in the hold to such an extent that the undermost layer of dynamite cases was submerged in water. It was necessary during the following days to pump continually in order to keep the barge afloat. Excellent packing prevented water from entering the dynamite cases. The mast of the "Veer Gebroeders" was cut down by the explosion, demolishing several cases of explosives in the uppermost layer. A heavy iron support, extending from one side of the barge to the other, was forced out of its rivets and broken in the middle, whereby the two broken ends penetrated the cases below. The whole of the barge, however, remained intact on the outside.

Opposite the "Elizabeth" at a distance of about 60 feet, the wooden barge "De Hoop" was moored. She was to have been loaded after the "Elizabeth", and the two barge captains were preparing to moor her along the bank at the moment of the explosion. This barge was burned down to the level of the water. Nobody was on board at the time.

At a distance of about 240 feet upstream, the empty wooden barge "Gezina" was moored. As a result of the indirect effect of the explosion, her deck was completely forced off. No one was on board.

At a distance of 330 feet from the "Elizabeth", and 75 feet from the "Gezina", the wooden Rhine barge "De Duif" was moored. Her deck was also forced out, and the cabin demolished. The barge captain and his children who were on board were not injured in any way.

As the effect of the explosion on the barges was decidedly an indirect effect, that is, suction in the direction of the center of the explosion, it must also be assumed that the damage to buildings ashore was caused by indirect effect, even though the direct effect was ascertained in a few cases of buildings in the immediate vicinity.

The effect of the explosion toward the west extended to something under 6000 feet, but toward the south and southeast it extended almost 9 miles. This was no doubt due to the direction of the wind.

Nearest the center of the explosion was a house at a distance of about 3280 feet. All the windows of this house were forced in. On the side facing the explosion there was a direct effect, and on the other side there was an indirect effect. The brickwork was cracked at the roof, and the pantiling was damaged on the side facing the explosion.

At a distance of 3940 feet, a farmhouse on a high level facing the explosion had all windows broken in front, and all the window frames and shutters were partly forced into the house. The roof was considerably damaged, and the tiles lifted up and slipped down. The walls were cracked at the roof in many places. The other side of the house showed only slight damage. This building was exposed to considerable direct shock. Missiles from the exploded barge were found in the vicinity.

At a distance of 4500 feet from the explosion, a farm facing the explosion had 2 windows broken by direct effect, and on the other side windows, doors and frames sustained considerably greater damage from the indirect effect of the explosion.

At a distance of 5400 feet, a house had windows broken on the side facing the explosion by direct effect, and on the other sides had very little damage from the indirect effect of the explosion.

In the small village of Schenkenschanz, 5,100 feet from the explosion, little damage was done except for broken window panes.

The Dutch village of Lobith, 4,500 feet away toward the north, suffered very little damage, which was mostly confined to broken window frames and dislodged tiles.

Zollkamer, 4,200 feet away towards the northwest, sustained slight damage only.

Dutch Spyck, which is situated in a northeasterly direction from the explosion, sustained much greater damage. The village consists of farms and houses at considerable distances from each other, and of several brickfields on the banks of the Rhine. The brickfields just opposite the explosion, and about 1800 feet away, had all the windows on the side away from the explosion thrown into the rooms by the indirect effect. The windows on the side walls had some panes of glass broken. There were no windows on the side facing the explosion. The roof was partly lifted, and a ceiling beam broken. A great number of the small fireplaces built on the brick furnace were turned over.

Another brickfield further down the river sustained only slight damage, broken windows and dislodged tiles.

At a distance of 2700 feet and immediately behind the dyke was a

dwelling house which suffered both by direct and indirect effect. All the windows toward the dyke were forced in, and about 1000 tiles were broken.

At a distance of 3000 yards, and on a higher level, a dwelling house had all its windows forced in on the side facing the explosion, with the exception of one screened by a large linden tree. This window was forced out of the house. A barn door was forced in by indirect effect.

At a distance of 2700 feet, another house sustained considerable damage to the roof, in addition to having several window panes and frames forced in, and some cracks in walls and ceilings.

At a distance of 6,300 feet to the southeast, a farmhouse had windows forced in and the roof lifted, so that a great many tiles fell.

At a distance of 6,600 feet to the southeast, the foresters' house had windows forced in. In the stable, which was newly built, the upper portion of the gable wall was slightly forced in.

At the villages of Brien en and Wardhausen, at a distance of 8,100 and 6,600 feet respectively, toward the south, only very slight damage was done to windows and roofs.

At Griethausen, a distance of 10,200 feet from the explosion, only slight damage was done to window panes. The house of the pilot, situated directly behind the winter dyke, which is 32 feet high, sustained the greatest damage. Six window panes in the house were forced out, and a portion of the roof was lifted. In another house, 300 feet behind the dyke, only one window was forced out. This house was larger and higher than anything in the neighborhood. A windmill nearby and seven small houses sustained no damage whatever.

On the opposite side of the Rhine, close to the Prussian frontier at a distance of about 7,200 feet, are the Lobith potteries on the banks of the Rhine. The great number of large roofs in this factory sustained some damage. In addition to this, many window panes and frames were forced in.

In the village of Elten, 10,500 feet away from the explosion to the northeast, the leaded glass windows of the church were forced in, and the windows in other houses broken.

Hochelton, at the same distance from the explosion and on top of a precipice 300 feet high, suffered comparatively little in spite of its altitude.

The old and dilapidated church in the village of Huthum, at a distance of 14,400 feet sustained some damage to the windows and mouldings.

In the town of Emmerich, 22,500 feet away from the explosion, considerable damage was done to plate glass, and to wares exhibited in show windows. In one shop, a large plate glass was lifted out of its frame, and left standing in the show window without sustaining any damage. A peculiar fact was noted, that wherever the affected buildings were protected

by other buildings, high trees, dykes, etc., they were invariably more affected than those which were in the open.

In the guano works on the banks of the Rhine, many windows were damaged, and the felt-covered roofs were torn by pressure of air at the corners.

The Dutch village of St. Heerenberg, 11,400 feet northeast, on a high level, sustained some damage in the line of broken windows; and also the village of Warbeyen, on the left bank of the Rhine, suffered in the same way.

To the southeast, glass was broken in the villages of Huisberden, Wissel, and Schloss Moyland. The town of Grieth, 9 miles from the explosion, was the furthest distance at which glass was broken.

Missiles were thrown 4,500 feet.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
House	None	Brick wall cracked, roof damaged.	3940
Area of structural damage.....			3940 feet
Charted at.....			1970 feet
Missiles thrown, up to.....			4500 feet
Glass broken, up to.....			9 miles

McALESTER, OKLAHOMA

Chart No. 70

On September 16, 1908, at 5 P. M., a magazine near McAlester, Oklahoma, was struck by lightning and an explosion followed.

The magazine was 16 x 20 x 10 feet and constructed of limestone with walls foot-and-a-half thick. The ground in the vicinity of the magazine was level prairie, except that to the west the country was slightly rolling with hills rising about a mile and a half away. There were no barricades around the magazine nor were there any large trees near the site.

The contents of the magazine which exploded consisted of 4000 lbs. of 30% and 15,950 lbs. of 40% dynamite, and 1000 kegs (25,000 lbs.) of black blasting powder, a total of 44,950 lbs. of explosives.

The building was completely demolished and not a stone left within a distance of 500 feet. A large jagged crater 50 feet in diameter and 15 feet deep was made in the hardpan soil on which the magazine stood.

A row of ten small frame dwellings were 400 feet west and extended in a line to 800 feet south of the magazine. Four of the houses were completely wrecked, six badly damaged.

Thirteen people were injured in these houses by flying glass, debris and falling chimneys, some of the injuries being quite serious. A woman was so badly injured by a falling chimney that she died the next day. The house in which this injury occurred was about 400 feet west of the explosion.

Freight cars on a siding, 200 to 250 feet away, were wrecked. A number of these cars were badly shattered and toppled over.

A coal mine "tipple" and engine room just within the 500 ft. zone north of the magazine was not damaged, except that a metal smoke stack, old and rusted, was blown down. The "tipple" and engine room were protected from the force of the explosion by a dump of slate and rock taken from the mine.

The stones in the walls of the magazine created a serious missile hazard. A man inside a house about half-a-mile from the explosion was killed by a stone which passed through after striking the ground 25 feet from the house. Another rock struck the house, smashed an iron bed and crashed through the floor.

Three cattle were killed by missiles about ¼ mile from the scene of the explosion.

In the business section of the city of McAlester, which was in a north-east direction from the magazine site, about 1½ miles distant, some plate glass was broken.

Summing up the damage done by the explosion, the following is the result:

Within 200 feet—total destruction.

From 200 to 500 feet—ten freight cars wrecked, four houses wrecked and six badly damaged, and a smoke stack blown down. Within this radius thirteen people were injured, one fatally.

From 500 to 1000 feet—nearly all chimneys on houses in this radius were blown down. Windows and doors blown in.

From 1000 to 2500 feet—a number of chimneys blown down, and windows broken.

Beyond 2500 feet—one man killed by a missile at 2640 feet, and plate glass broken in McAlester.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Dwellings	No barricade	Chimneys, blown down doors and windows broken	1000
Area of structural damage			1000 feet
Charted at			500 feet
Missiles thrown, up to			3960 feet
Glass broken, up to			1½ miles

LOWELL, MASS.

Chart No. 67

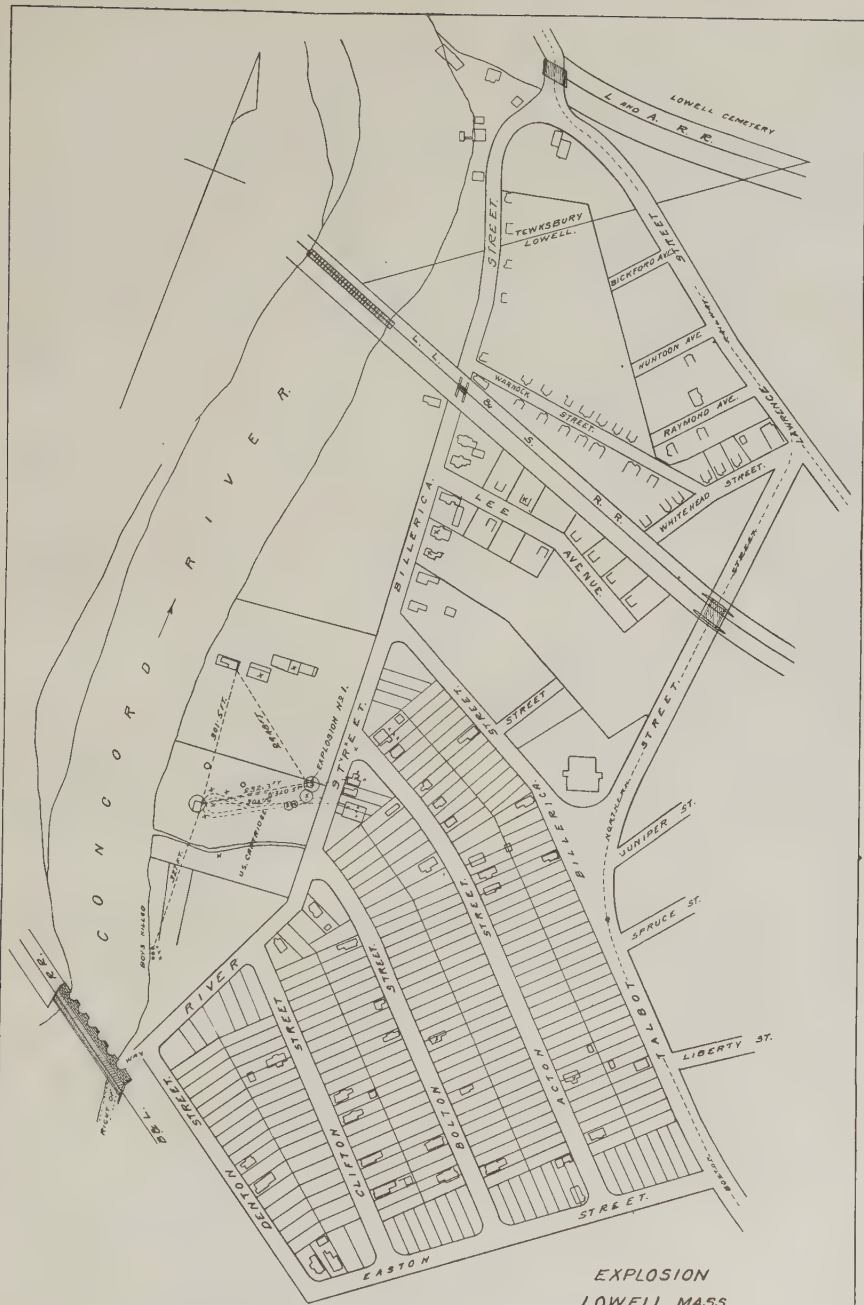
A disastrous explosion occurred on the 29th of July, 1903, at Lowell, Mass., in a powder magazine containing black powder and dynamite, involving a powder wagon loading at the door, and a second magazine.

The portion of the territory of the town of Tewksbury, in which the magazines were located, was bounded on the north by the city of Lowell, on the south by the town of Billerica, and on the west by the thread of Concord River. The width of this part of the town was about 4500 feet. A bridge crossed by the main line of the Boston and Maine Railroad, known as the Six Arch Bridge, spanned the river, while to the north was the bridge of the Lowell, Lawrence and Salem Railroad. Between these bridges the banks of the river were low, but slightly elevated above the surface of the water, the land on either side being meadowland. On the right shore this level land between the bridges averaged about 325 feet in width; beyond this, to the northeast, east and south, the ground was somewhat higher, an uneven rolling territory.

In 1874 two acres of this meadowland lying between the two railroad bridges was purchased, and the same year the first powder magazine was constructed on the lot. The building was rectangular in form, 24 feet long, 18 feet wide and 12 feet high. The walls were 16 inches thick, including an air space of four inches and were built of brick resting on a trench wall of stone. It had a hard gravelled flat roof, and was provided with double iron doors opening to the east. The floor was made of some soft wood, built about two-and-a-half feet above the ground. The magazine was unequally divided by a partition of slats extending to the roof. It was not barricaded or protected in any way.

In 1886 a second magazine was built, 233 feet distant from the first magazine to the east, which for convenience in this report we will call Magazine No. 2. It was a brick building, 14 feet square.

At the time of the erection of these magazines the territory immediately around them was practically unsettled. The meadowland on which they were built was covered with low-growing river bushes, while to the east and south was a houseless territory with scattered trees and bushes growing over it, and in some places swampy and unsuitable for cultivation. There were only two or three houses in the neighborhood, but in 1891 a territory known as "Riverside Park", lying easterly and southerly of these magazines was purchased by a land company, divided into lots, streets laid out, and in the same year an auction sale of the lots was held. Building was immediately begun, and three-quarters of the houses standing at the time of the explosion



EXPLOSION
LOWELL, MASS.
JULY 29, 1903.

0 100 200 300 400 500
SCALE - FEET.

were built during this development. After 1895, the increase in dwelling houses was small.

The town of Tewksbury did not take any action or order of any kind, in regard to the magazines, though the town had grown out into their immediate neighborhood. The magazines were badly located, since within a radius of less than half-a-mile were the homes of 486 men, women and children, gathered in 105 families and occupying 92 dwelling houses.

On the 6th of July, 1903, an employee of the owner of Magazine No. 1 called attention to the fact that something of a liquid character was leaking on the floor of one of the compartments of the magazine and apparently came from the boxes of dynamite stored in the next compartment. This leakage was found to be exuded nitroglycerin, and the floor was found to be stained for two or three feet on each side of the partition. It was decided to remove all the powder from the magazine, take out the partition, and replace the floor.

One compartment of the magazine contained 17500 lbs. of black powder and the other contained 1175 lbs. of black powder and 1600 lbs. of dynamite, making a total of 20,275 lbs. of explosives.

On the morning of the 29th of July, the stock of powder in the first compartment, 17,500 lbs., was loaded onto three wagons. It was planned to drive these wagons some distance to an open field, and leave them there, drawn up and covered with canvas, until the floor was taken up and a new one laid, then bring the powder back. The drivers of the teams were to have nothing to do with handling the powder, which was to be done by experienced powder workers.

By nine o'clock in the morning, two of the wagons were loaded and drawn up 22 feet apart at a point near Magazine No. 2.

The third wagon was standing at the door of Magazine No. 1. The carpenters who were to replace the floor had unloaded their lumber and were sitting on the grass waiting for all the powder to be taken out of the building. The explosive in the second compartment had not yet been removed.

At this point the foreman in charge of the work entered the magazine carrying a jug filled with some liquid, which he poured on the patch of nitroglycerin on the floor. After waiting a few seconds, he started to scrub it around with an old broom which was used to brush out the magazine. He had been instructed to sweep up all sand, sawdust, or other dirt, and then thoroughly scrub the floor with a hot solution of carbonate of soda to remove the nitroglycerin from the surface of the wood. What the foreman was pouring on the floor could not have been carbonate of soda, for in a few seconds it started to smoke on the spot. The foreman called for water, and some of

the men grabbed up some pots and ran to the brook to fill them. Some few pails were poured on the floor before the explosion.

The magazines and the three teams loaded with powder standing near them were entirely demolished; hardly a trace remained, except deep holes in the ground, indicating where they had stood. The brick, iron, wood and other materials, of which they were composed, flying in all directions with terrible force, as well as the shock of the explosion itself, were dreadfully destructive to human life in the immediate vicinity. Of the persons engaged in work in or about the magazine, twelve in number, seven lost their lives. Nineteen persons in all were instantly killed, and over fifty were injured. One man in a house about 78 feet away from the second magazine was practically blown to pieces. Five boys bathing in the river 450 feet away were found dead, whether from shock or from drowning, due to the sudden rise of the water, was not known.

Damage to buildings extended to the limits described as bounded by the Concord River, Lawrence, Talbot, Easton and Denton Streets. Lawrence Street represented the outskirts of the district covered, which varied in distance from 1350 to 1650 feet from the explosion, and 1650 feet was therefore taken as representing the extent of serious structural damage.

The greater part of the damage to the neighboring town was undoubtedly due to the explosion in the second magazine, the wagons laying a train from the first magazine to the second. On the day of the explosion, 27,500 lbs. of gunpowder had been placed in the second magazine, and with the 20,275 lbs. already given as the amount in the first magazine and wagons, the total amount of explosives involved was 47,775 lbs.

The Judge's finding in this inquest is quoted below, as an interesting example of the popular attitude towards the storage of explosives:

"I find on the evidence that these magazines were, on the 29th day of July, 1903, and for a long time previous, nuisances at common law and dangerous to human life and property. This terrible explosion is only the awful blow of a direful menace which night and day for eight years at least has hovered like demon of death and destruction over the heads of the inhabitants of that portion of Tewksbury known as Riverside Park, and over those who for business or social occasion have walked or driven upon the streets of that locality. Year in and year out, this monster menace has existed in this valley community—a thing known, though not comprehended. It was unlike other overshadowing threats with local traditions or thrilling historical events. The Neapolitan, who lives ever in the shadow of the volcano, appreciates the game of life which he daily plays; he gambles with its cards with open eyes; he fully understands that Vesuvius has held at all times all the cards and won the game. The menace that nature offers to the

mountaineer of mountain slide, or that which by the rage of the sea or storm she desolates Galveston, are open, bold and daring possibilities; the risk is there; nature may or may not win. But this insidious monster menace, unlike wave or wind, mountain slide or volcano, lay not in the hand of nature. Man placed it where it wrought its terrible work; it had no local precedent of personal history; it was but a thing stored in brick walls, handled by men, drawn by horses, a seeming necessity of daily work."

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwelling houses	None	Seriously injured	1650
Area of structural damage.....			1650 feet
Charted at.....			825 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			2 miles

BRIDGEPORT, CONNECTICUT

Chart No. 20

On May 14th, 1906, at 4.25 A. M., there was an explosion in a powder magazine about a half mile from the boundary line of the city of Bridgeport, Connecticut, involving two other magazines, and a total amount of 48,675 pounds of explosives, black or smokeless powder.

There were seven powder magazines, all located on 300 acres in wooded land, well protected by trees, except for Magazines No. 6 and No. 7, where the surrounding trees were rather few. Considering the proximity to the city of Bridgeport, and the fact that the country surrounding it was so well built up, the magazine location was a remarkably good one.

Magazine No. 6 was about 10 feet below Magazine No. 7. Magazines 3, 4, 5 and 7 were on about the same level, but a ridge about ten feet high extended between No. 7 and the others, running north and south. Nos. 1 and 2 were on the same level as No. 6, with a ten foot ridge between. Between magazine No. 6 and No. 3 there was quite a large ridge, possibly 20 feet higher than the elevation of No. 6.

Magazines No. 3, 4, and 5 were on a line running approximately north and south. To the north there was considerable wooded land; to the northeast, east and southeast there was very little wooded land for some distance from the magazine. To the south of Magazines 6 and 7 there was quite a valley running down to the Sound, the works of the Ammunition

Loading Company, owners of the magazines, being approximately south of these magazines. Immediately southeast of Magazines 6 and 7, there was a rocky hill about 15 feet high, and this hill undoubtedly was a protection to the city of Bridgeport.

Between Magazine No. 4 and the city on the south, there were trees on the magazine property itself, but to the south of Magazines Nos. 3, 2, 1 and 8, there were not many trees and no high land worth mentioning. To the north and northwest the country was well wooded.

The explosion happened at 4.25 A. M., when no one was about, so that there were no fatalities. No cause was found for the explosion, although it was suggested that some malicious person with a grudge against the company had caused the explosion in one of the magazines. This could readily have been done, and the evidence destroyed by the explosion. The time of night at which it occurred would be a time naturally selected for such work.

One witness reported that at the time of the explosion he was awakened by what seemed to him one loud report, and that he got out of bed, went to the window, and heard a second report, which seemed less loud, and almost simultaneously a bright light flared up in the direction of the magazines, lasting for a few minutes. This was probably the smokeless powder burning. The evidence as to the number of explosions, however, was somewhat contradictory, many witnesses testifying to two, others reporting that they heard three or four explosions.

The quantity of explosives involved was as follows:

Magazine No. 3—5 kegs of black powder, 459 kegs of smokeless.
Magazine No. 4—165 kegs of black powder, 198 kegs of smokeless.
Magazine No. 6—791 kegs of black powder.
Magazine No. 7—892 kegs of black powder.
Total—1853 kegs, 46,325 pounds. 657 kegs, 2,475 pounds.

The smokeless powder did not explode.

All the evidence with reference to the explosions indicated that the most violent explosions were the first, and it will be noted that in Magazine No. 7 there were 892 kegs of powder and in Magazine No. 6 there were 791 kegs. Probably the contents of Magazines 6 and 7 exploded first, then the contents of No. 4, and Magazine No. 3 caught fire and burned.

The craters left where the magazines had stood were slightly larger than the magazines, and from 5 to 7 feet deep. The roof of Magazine No. 5, 200 feet from No. 4, and somewhat protected by trees, was badly crushed in. Magazines 1, 2 and 8 were not affected by the explosion. In the cases of Magazines 6, 7 and 4, the contents and materials of which the magazines were constructed were entirely destroyed.

Outside of the magazine property, the resulting damage to buildings

was somewhat surprisingly light. The building which suffered the most was the poor house, located about 1760 feet to the south. A large number of windows and window sashes were broken, plaster knocked down, and chimneys knocked over. The barn was somewhat damaged, the sides pulled loose, apparently by the vacuum formed by the explosion. Buildings on the top of the hill to the southeast were similarly damaged.

In the valley to the south, the damage was slight and freakish, consisting mostly of broken glass. One building lost but a few lights in the upper portion, while a building to the south of it lost a large number of lights, and in some cases the sashes, though this building was farther from the explosion than the first building. To the southwest, property was protected by the small hill before mentioned, and damage was limited to plate glass windows on the lower floors of buildings. Breakages occurred on the sides of streets farthest away from the explosion, almost invariably on the ground floor. Plate glass was here broken at a distance of two miles. Property to the west and north was protected by the wooded land, and complaints from property owners in these directions were few.

There were hills to the northeast and southeast of the scene of the explosion. The force of the explosion between these hills was apparently unbroken for a long distance, and an authenticated report was received of the breakage of two plate glass windows in New Haven, 18 miles away. The town of Stratford, two miles to the east, suffered the loss of a great many windows.

The rather limited damage which occurred to the south and west may be attributed also to the direction of the wind.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Poor house and barn	Trees	Windows and sashes broken, plaster down chimneys knocked over Sides pulled loose.	1760
Area of structural damage.....			1760 feet
Charted.....			880 feet
Missiles thrown, up to.....			No record
Glass broken, up to.....			18 miles

JACKSON, UTAH

Chart No. 59

There was an explosion on a freight train of the Southern Pacific Railroad on February 23rd, 1904, on a switch near Jackson, Utah.

The car containing the explosives, 1000 cases of 50 pounds each, or

50,000 pounds of low powder, was shipped from Salt Lake City on February 13th, and was bound for Tacoma, Nevada. On the cut-off between Tacoma and Hogup, Utah, it met another train on the switch at Jackson in head-on collision, attributed to defective air brakes and the carelessness of one of the engineers.

The freight car containing the powder was directly back of the engine. After the collision a fire broke out, but the powder did not explode until sufficient time had passed to enable the operator at Jackson to send a message to the effect that a collision had occurred, and that the outfit was on fire; but the powder exploded before his message was complete. The interval of time that elapsed proved that the explosion was caused by fire, not collision.

The loss of life was considerable, the dead numbering 23. There is no record of the number of injuries.

One engine was completely demolished, and the other badly damaged, and a number of freight, water, and gravel cars were destroyed.

The farthest point of structural damage was done to a house in an exposed position on a hill at a distance of about half a mile.

SUMMARY

Building damaged	Protected	Extent of damage	Feet distant from explosion
House on a hill	No	Structural	2640
Area of structural damage.....			2640 feet
Charted.....			1320 feet
Missiles thrown.....			No record
Glass broken.....			No record

SANTANDER, SPAIN

Chart No. 86

On November 3rd, 1893, a terrible explosion involving great loss of life occurred at Santander, Spain.

The Spanish steamer "Cabo Machichaco", 1213 tons register, Vaco Andaluz Company, arrived at the port of Santander with a general cargo, consisting of 2,000 tons of iron, many cases of petroleum, a few barrels of wine and some sacks of flour for ports along the coast, and 30 cases of dynamite for Santander.

Before reaching the quay, the ship had obtained permission to unload, in direct contravention of the harbor regulations respecting vessels with explosives on board. She was found to be on fire, and yet, astounding to



relate, she was allowed to be moored to the quay. The dynamite was quickly unshipped, and removed to a place of safety on shore. The agent denied that there was any more dynamite on board. It speedily became apparent, however, that such was very far from being the case. There was in fact a further enormous quantity on board, amounting to about 1780 cases, which was not declared.

In the meantime, the quay was crowded with spectators to see the burning ship. Many notables were present. About two hours and a half after the outbreak of the fire, a tremendous explosion took place, blowing up the steamer, part of the quay, and killing the majority of the people upon it. Spars, sails and all sorts of fragments were hurled in every direction, killing and injuring people at considerable distances. Some buildings were set on fire by burning debris, and serious damage was done to a great part of the town, to ships, quays, etc.

It was estimated that the number of people killed was 510, including those that died from injuries within a month, and about 2000 people were injured. Several people were killed by falling debris at distances probably within a radius of 900 feet, which was estimated as the distance to which rails and heavy objects were thrown. No doubt in some cases injuries from falling debris were suffered at greater distances.

As regards the quantity of dynamite that exploded it was estimated that 1,200 cases of 55 pounds each, or 66,000 pounds in all, was involved. This was stored in the forehold of the boat. The No. 1 dynamite which exploded was packed in cardboard packets, weighing $5\frac{1}{2}$ pounds, and wrapped in paraffin paper. Ten of these packets were placed in a wooden box, lined with the same kind of paper. Only the dynamite in the forehold exploded, an additional 38,500 pounds in the afterhold remained in the wreck unexploded. Half of the steamer was completely wrecked, and thrown in all directions with cargo and gear, but from the engine room to the stern, the hull remained.

It was low tide when the explosion occurred. The steamer was fastened to the wharf end, about 100 feet from the shore, and was immersed 16 to 20 feet. The ship's hold was half overflowed, and submerged to the waterways. She was therefore surrounded by a considerable amount of water, which undoubtedly served as a resistance against lateral effects. If the ship instead of being submerged had been afloat, and overlooking the wharf, the result of the explosion must have been of much greater ruin.

The explosion produced an enormous wave, which overflowed the quay, but did not destroy the wharf to which the steamer was secured.

Four small steam launches near the "Cabo Machichaco" went down with all on board. The English steamer "Eden", about 820 feet away, had its mainmast fractured, and some injury to its deck. Two or three steamers

at distances of 330 to 495 feet from the explosion did not suffer in their hulls, but only in their decks, spars, etc., which were struck by projectiles.

The damages on shore were numerous. The first and second tiers of buildings near the quay and within 1650 feet of the explosion suffered great interior wreckage; walls, ceilings, and floors fell in, and caused many injuries and conflagrations; but the external walls and roofs of most of these houses remained standing, and could be utilized for rebuilding. No building was completely destroyed or fell to the ground, although many were only 330 feet from the explosion. Effects from the ground shock were not noticeable, but the air concussion was much felt, and reached to a great distance.

The distances reached by missiles from the wreckage and cargo of the steamer were very considerable. The general area of danger, taking into consideration the number of projectiles, was considered as 2640 feet. But in some cases, projectiles were thrown much farther. Two pieces of an anchor, weighing respectively 77 and 88 pounds, fell close to the Atalaya Signal Tower, a distance of 3960 feet, 248 above sea level. Other pieces fell at a distance of 4620 feet on level ground, on a promenade, causing several deaths.

All the buildings within 3330 feet were left without windows, and even those on the third and fourth tiers from the quay had their windows damaged. Glass was broken for a distance of five miles.

Unfortunately the chapter of accidents caused by the transport of dynamite on the "Cabo Machichaco" did not end with the destruction of the steamer on November 3rd, 1893. The explosives in the afterhold, estimated as 38,500 pounds of dynamite, soon became a further danger to the town, owing to the exudation of nitroglycerin, which always occurs when dynamite becomes soaked with water. This exuded nitroglycerin, being heavier than water, sinks, and being easily exploded by friction, it becomes a real danger. After 2,530 pounds had been removed by a special pump, a technical committee was appointed by the government to study the method of proceeding. The deposit of nitroglycerin was supposed to be in the bilge and bunkers. The cylinder and portions of the engine were removed by diving operations, in which submarine electric lamps were employed. The work went on until March 21st, 1894.

On that date the second explosion occurred. The divers were engaged in discharging the cargo in the afterhold and the explosion caused the death of all the men employed to the number of 19. The accident occurred through the carelessness of the divers, who were well aware of the presence of nitroglycerin, and had been strongly warned not to touch the cargo that was in the immediate neighborhood of the dangerous cases.

This great final explosion, nearly five months after the first, completes the history of the disaster.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Buildings near quay	Water	Interior wreckage, walls, ceilings, and floors fell in.	1650
Area of structural damage.....			1650 feet
Charted.....			1650 feet
Missiles thrown, up to.....			4620 feet
Glass broken, up to.....			5 miles

GOLDEN GATE HARBOR, SAN FRANCISCO, CAL.

Chart No. 117

A serious explosion occurred on board a stranded vessel off the entrance to the Golden Gate, San Francisco, on the night of the 15th of January, or, more exactly, at 12.34 A. M. on the morning of the 16th.

A small sailing vessel, the "Parallel" of 142 tons register, laden with explosive, mineral oil, lumber, pig iron and coal, bound for Astoria, ran ashore at about 9.30 P. M. on the 15th of January on some rocks a short distance from the Cliff House Hotel.

The vessel, after getting out of the harbor, was becalmed in a heavy swell and fog, and drifted into the surf. The captain and crew, knowing the dangerous character of the cargo, and that the vessel's fate appeared to be inevitable, abandoned her. She afterwards grounded on the rocks, against which she was beaten by the surf.

Almost exactly three hours after grounding, her cargo exploded with tremendous effect. The Cliff House, only 800 feet away, and 84 feet above sea-level, and the life saving station, a large concert room on the beach and other buildings were wrecked. Alfred Sutro's conservatory on the heights above was shattered to atoms, and all the windows in his house broken. Huge pieces of rock were projected to considerable distances, in some cases over half a mile. The "Parallel" herself was blown to pieces.

The sound of the explosion is said to have been terrific, and was heard for a hundred miles, at Oakland, San Jose, and even at Sacramento. Glass was broken at a distance of 6 miles.

No one was killed in this explosion, but three members of the life saving crew, who had built a fire on the beach and were watching the wreck, were severely injured. The men in the life saving station thought the explosion was an earthquake and tidal wave.

The explosion occurred so close to Seal Rocks that it was thought immense numbers of seals would be killed by the concussion, but such was not the case. Only two dead seals were seen.

The exact amount of explosives on board the "Parallel" was 1635 cases of 50 pounds each, or 81,750 pounds, composed as follows:

285 boxes of Giant powder, No. 1	14,250 pounds
850 boxes of Giant powder, No. 2	42,500 pounds
500 boxes of Judson powder	25,000 pounds
	<hr/>
	81,750

An attempt was made to explain the explosion as occurring from fire catching the ship from four coal oil lamps left burning when the ship was abandoned. But the ship was not observed to be on fire, and it was considered that the surf would have extinguished any fire long before the explosion, which did not occur until three hours after the vessel grounded.

An opinion was expressed that all the Giant Powder did not explode, for a large number of the boards which formed the cases in which the cartridges were packed, were not at all damaged. They must have fallen apart while the vessel was battering against the rocks.

This explosion is unique in some of the circumstances attending it, and also in the amount of nitroglycerin compound which went off. It recalled some of the circumstances of an explosion which occurred in July, 1886, at Havre, of a vessel laden with gunpowder and dynamite which had run aground opposite the Hotel Frascati. The explosion did not occur until 24 hours after the vessel ran aground, and was attributed to exuded nitroglycerin.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Cliff house	Water	Almost completely wrecked	800
Area of structural damage			800 feet
Charted			800 feet
Missiles thrown, up to			2640 feet
Glass broken, up to			6 miles

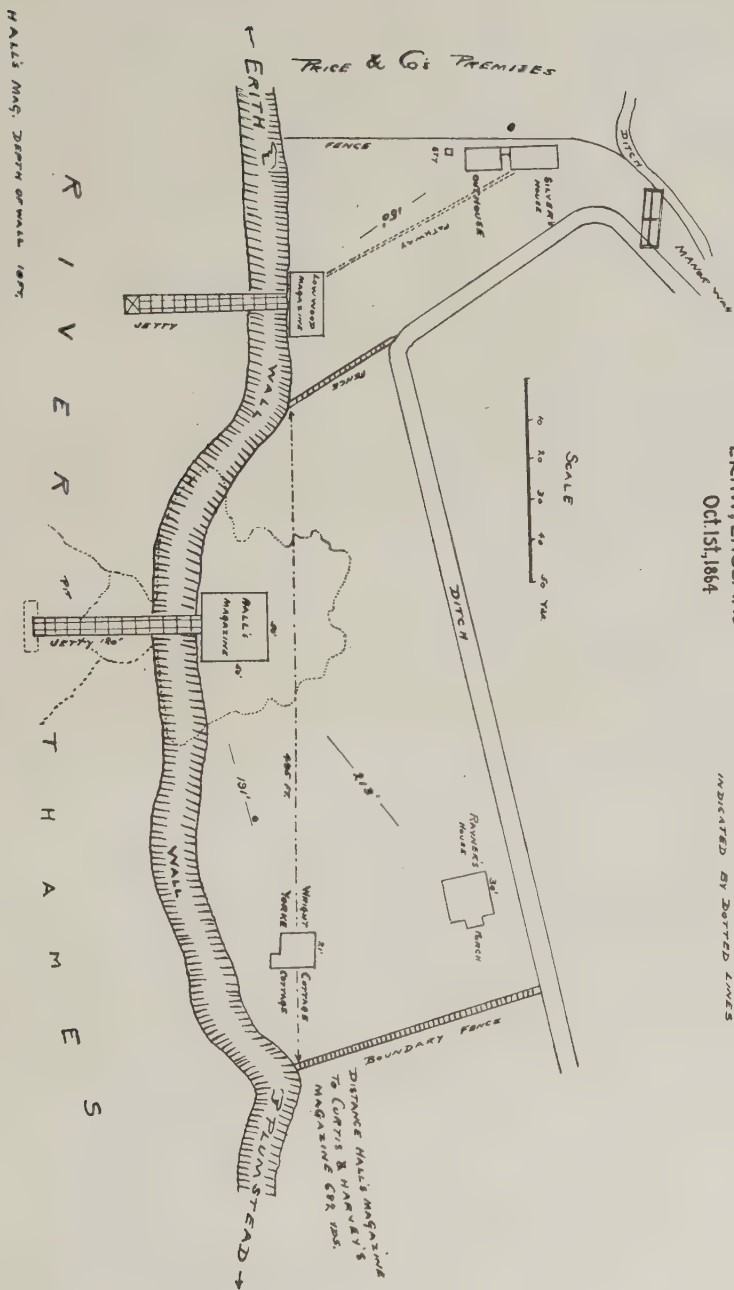
ERITH, ENGLAND

Chart No. 37

On October 1st, 1864, a serious explosion took place on the south bank of the Thames near Erith, England.

EXPLOSION ERITH, ENGLAND Oct. 1st, 1864

EXTENT OF GROUND TAKEN UP BY THE EXPLOSION
INDICATED BY DOTTED LINES



PLAN DRAWN FROM ACTUAL SURVEY BY MR. H. V. MARRINER OF THE
ERITH ANCHOR FOR INSPECTION OF CORONER JURY

Erith was an ancient town, first mentioned in a Latin Charter of the year 695. It possessed an historic church dating from Saxon times, and rebuilt under the Normans. This old parish church rose up from the marshes a little distance from the town, probably in its main structure much what it was when the famous meeting took place within its walls on November 19th, 1215, between the discontented barons and the commissioners of King John, to ensure the adherence of the king to the terms of Magna Charta.

At the time of the explosion in 1864, the town had a population of about 4000 people. Two miles to the west, and about an equal distance from the town of Belvedere, stood two powder magazines, in Plumstead Marshes on the margin of the river. The magazines stood about 135 feet apart. On October 1st, the day of the accident, the larger magazine, a stone building about 50 feet square, contained 750 barrels of black powder, and the smaller magazine, 28 by 48 feet, contained 90 barrels. Two powder barges, the "Good Design" and the "Harriet", loaded with 200 barrels of powder, were moored at wharves projecting 120 feet into the river near the large magazine. An explosion from an unknown cause occurred on one of the barges, and was communicated to the magazines. All reports show three separate explosions; first, 22,000 pounds on the barges; second, 83,500 pounds in the large magazine; third, 9,900 pounds in the small magazine. It seems logical to conclude that the second explosion of 83,500 pounds produced the distant damage.

The barges were split into fragments, and not one stone remained upon another in the magazines. A crater 75 feet long and 5 feet deep was formed, and 150 feet of river wall was destroyed. The shock was felt at London, 15 miles away.

The masters and mates of the "Good Design" and the "Harriet" were instantly killed, also two men working on the river bank. At the cottage of one of the magazine keepers, about 200 feet away, the keeper himself was killed, his wife and son injured, and his daughter received such serious injuries that she died soon after. The other keeper escaped with slight injuries, but his niece was killed at his cottage about 210 feet from the magazine. This made a total of nine people killed and three injured in the explosion.

Three other magazines situated at distances from a quarter of a mile to a mile received only slight damage.

Except for a few cottages, there were no buildings in the immediate vicinity of the magazines.

The old Erith Church, mentioned above, 4440 feet away from the scene of the accident, had its ceiling blown in and part of the roof damaged. The

windows and some of the mullions were scattered over the pews, and one of the massive freestone gargoyles inside the church was snapped off.

The railroad station at Belvedere, 4660 feet away, had part of its walls thrown down as a result of the explosion, and the walls of a brick building under construction at the station were disturbed, and partly thrown down.

At distances of from 6600 to 9000 feet, walls of houses in an exposed position were slightly cracked; but real structural damage did not extend in any instance beyond 4660 feet.

There was much glass breakage in Erith and Belvedere, and all the windows were smashed in a row of houses on the brow of the hill leading to Bexley. Generally speaking, glass was broken up to a distance of 15,000 feet, and in particular instances up to 10 miles.

Some charred fragments of powder kegs were found at Abbey Wood, a distance of 2½ miles.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Railroad station at Belvedere	No protection	Wall damaged. Brick wall under construction thrown down.	4660
Erith Church		Roof damaged, and part of ceiling brought down.	4400
Area of structural damage.			4660 feet
Charted.			2330 feet
Glass broken, up to.			10 miles

SAN ANTONIO, SPAIN

Chart No. 174

An explosion involving a considerable amount of dynamite took place on August 23rd, 1913, in a magazine near San Antonio in the Province of Lerida, Spain.

There was stored in the magazine at the time 103,400 pounds of dynamite, to be used for blasting operations in connection with the hydro-electric works which the Ebro Irrigation and Power Company had in course of construction in the province. The building was constructed of a light composition of clay and lime plastered on cane lattice, especially suited for the purpose. No protection of the magazine from outside property was needed, on account of its location on top of a hill, at a great distance from the village and camp.

At about 7.30 P. M. on the evening of August 23rd, the magazine was

struck by lightning, exploding the dynamite, and instantly killing the guard at the magazine. Between 18 and 20 persons were injured, either through shock caused by the explosion, or by flying glass.

All damage was done in a straight line from the place where the dynamite store was situated, affecting the company's camp and a place on the hills called Talarn. Owing to the exceptionally light material used in the construction of the building in which the dynamite was kept, no missiles of any kind were thrown, and consequently no injuries on that account are reported.

In regard to damage to surrounding property, the only serious damage was caused to a house for road-construction men about 327 feet distant from the explosion. More or less serious wreckage was caused to the bungalows and the hospital which the company had erected for their employees at a distance of about 1640 feet from the dynamite store.

The extent of the area in which glass was broken was about 1650 feet.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Bungalows & Hospital	By situation	Roofs blown off, timbers broken.	1640
Area of structural damage.....			1640 feet
Charted.....			1640 feet
Missiles thrown.....			None
Glass broken, up to.....			1650 feet

JOHANNESBURG, SOUTH AFRICA

Chart No. 60

One of the most tremendous, and, in its effects, certainly one of the most serious explosions up to that time, occurred at Johannesburg, South Africa, on the 19th of February, 1896.

About 55 tons, 110,700 pounds of blasting gelatin exploded on the siding of the Netherlands-South Africa Railway Company at Braamfontein, while being unloaded from eight railway trucks, which had been standing in the sun for three days. A truck loaded with 90 cases of detonators was shunted by a locomotive, and exploded, causing the eight truck loads of dynamite to do the same.

The locomotive ran into the trucks in consequence of the switch being wrongly turned, and doubtless caused the explosion at the moment of collision. At the same time, various acts of carelessness and neglect were being committed that might have brought about the explosion.

The evidence brought out the fact that the trucks containing the blasting gelatin had been left standing for 3 days without proper supervision, in a place surrounded by human habitations, and that the switch was not capable of being securely locked; also that sufficient care had not been hitherto taken in the conveyance of explosive to the magazine. Dynamite and detonators had been carried on the trolley, and cases containing blasting gelatin had on several occasions fallen off the trolley in transit. Further, it appeared that when explosives arrives at the magazine, the magazine keeper was not always there to receive them. Lastly, it was ascertained that the packing of this particular consignment was not in accordance with the law. Among other defects, the wood of the cases was not of the required thickness, and the lids were not strengthened.

In view of these irregularities, and that the shunting train was going at ordinary shunting speed, and that the brake and driving apparatus of the locomotive were not defective, it was considered that the impact was not entirely to blame for the accident, which would probably have been avoided had all else been in order.

More than 50 people were killed in this explosion.

The explosion took place about 900 feet to the west of Johannesburg station. A crater about 300 feet long by 65 feet wide by 30 feet deep was excavated in the soft ground. There was total destruction within a radius of about 990 feet, while from that distance to 1980 feet all buildings were shattered. Roofs were battered in up to about 3,000 feet. The buildings were chiefly of corrugated iron and mud, and were therefore not of a substantial character.

Fragments of iron were picked up at over 9000 feet. Windows were generally broken up to about 6,000 feet, and in one direction, where the ground sloped toward the site, windows were broken up to 15,000 feet.

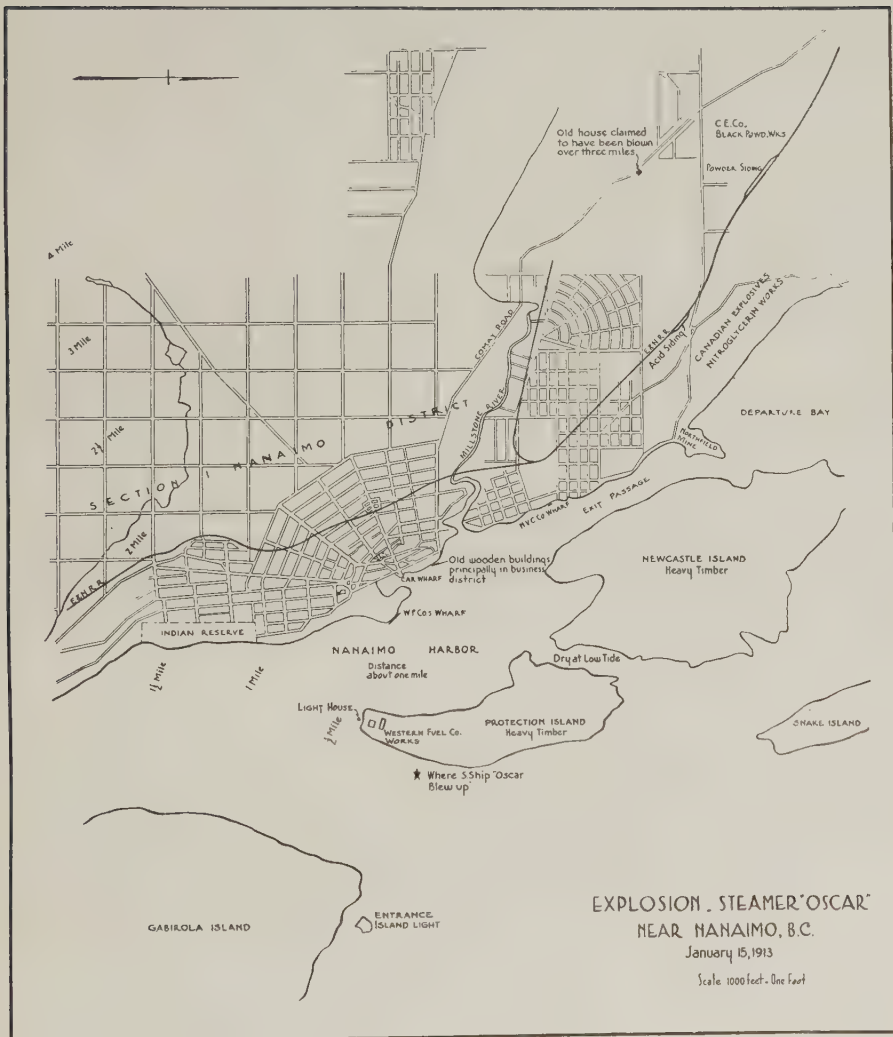
SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Corrugated iron & mud	None	Shattered and roofs battered in.	3000
Area of structural damage.....			3000 feet
Charted.....			1500 feet
Missiles thrown, up to.....			9000 feet
Glass broken, up to.....			15000 feet

NANAIMO, B. C.

Chart No. 175

An explosion occurred on board the steamer "Oscar" in the harbor of Nanaimo, Vancouver Island, B. C., at 1.55 P. M., January 15th, 1913.



The "Oscar" was a steam freighter of 120 tons burden, and was distinguished by the fact that her smoke-stack was forward of her pilot-house. She was carrying 1900 cases of 40% dynamite, stacked on the deck from the boiler casing forward to the bow of the ship, and 50 kegs of black powder in her hold, a total of 96,250 pounds. (Note).

Shortly after one o'clock in the afternoon, fire from an unknown cause broke out in the boiler room, and the captain and crew of six men beached the steamer immediately on Protection Island, about a mile from the town of Nanaimo. Twenty-five minutes after the fire was discovered, the explosion took place. The captain and crew escaped in time, and no lives were lost.

The steamer was entirely destroyed. Immediately after the accident, the captain went back to the place where the "Oscar" had gone ashore, and found that there was absolutely nothing left of the vessel. There was no record of any wreckage being found, except a piece of the anchor, weighing 150 pounds, which was picked up two miles away.

In the town of Nanaimo, 20 or 30 people were injured, but no one seriously, by falling glass.

There was no real structural damage in Nanaimo. The principal damage there was broken glass; almost all the windows in the business section were broken. It was estimated that from 25,000 to 30,000 square feet of glass was smashed. The greatest distance of breakage was 15,000 feet. Some plaster was shaken down, and doors required resilling, notably in the Court House, which received the full force of the explosion.

On Protection Island, the Western Fuel Company's plant suffered damage to their boiler room, and some of their buildings were totally destroyed. The roof was blown off the fan house. The distance from the nearest plant building to the "Oscar" was 500 feet, and much damage was done up to 1100 feet.

NOTE:—Reports varied as to the amount of powder on the "Oscar". An early report showed 110,786 pounds of high explosives and 1375 pounds of black powder, a total of 112,155 pounds. Another figure, used in the American Table of Distances, gave 124,450 pounds, due to an error in calculation.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Plant buildings	Water	Destroyed or badly damaged	500 to 1100
Area of structural damage.....			1100 feet
Charted.....			1100 feet
Missiles thrown, up to.....			2 miles
Glass broken, up to.....			15000 feet

FAIRCHANCE, PA

Chart No. 180

At 15 minutes past 9 o'clock, September 9, 1905, a series of explosions started on the Rand Black Powder Factory and extended over a period of a minute and a half.

The factory consisted of about 20 buildings, frame structure, spread over 20 acres of ground, enclosed by a tight board fence, 12 ft. high. There were no barricades or protection around the explosives buildings except a few willow trees.

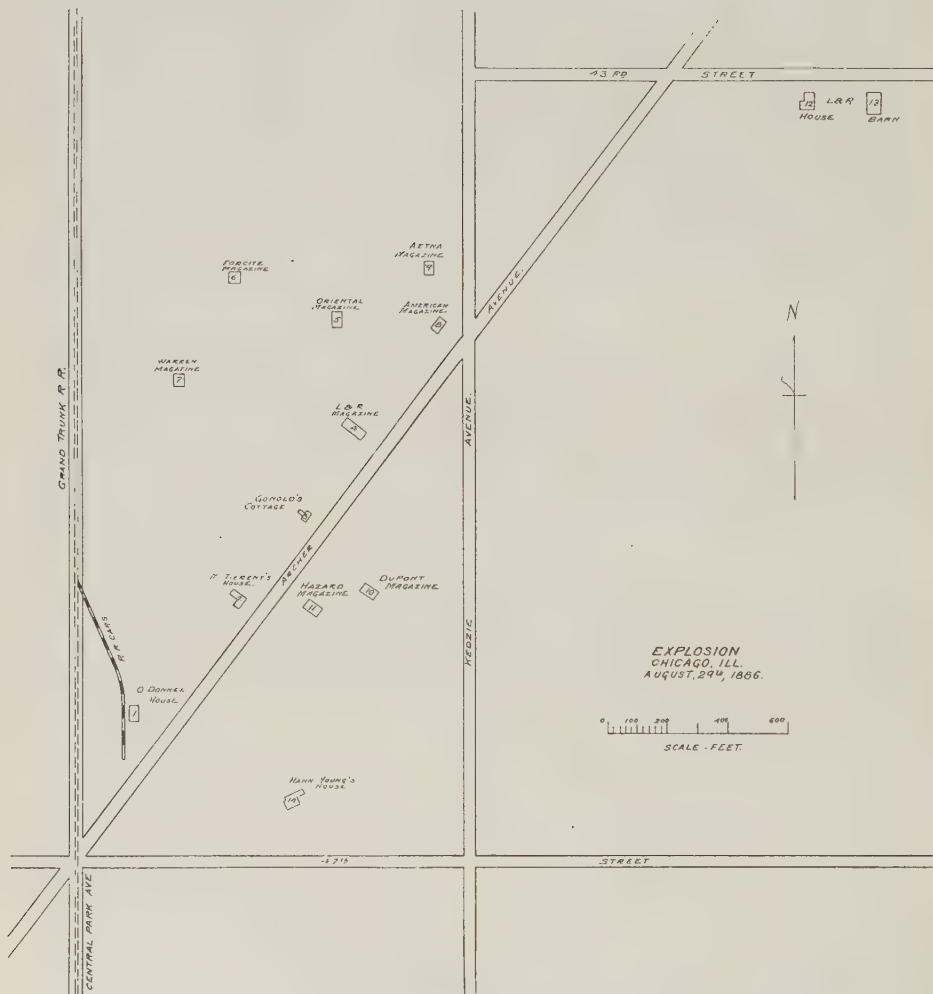
The plot of ground on which the factory buildings were located was 5 miles from Uniontown and about $\frac{1}{4}$ of a mile from Fairchance and was protected slightly on the right side by a small hill, while on the left side the land was practically flat. Only in the direction of Fairchance were there many houses, and although there was a hill between, many of these were severely damaged; in fact, all buildings within $\frac{1}{4}$ of a mile of the factory suffered more or less structural damage.

The first explosion took place in a barrel type mixing house, located in the southwestern end of the group of buildings comprising the factory. This was followed by explosion in the glaze mill, some 200 ft. north of the mixing house.

The third explosion was in the pack house, 100 ft. northeast of the glaze mill, then came an explosion at the combined dynamite magazine and nitrate of soda storage, 375 ft. northeast of the pack house. The fifth explosion was a black powder magazine which was 75 ft. from the dynamite magazine, and about the same time an explosion occurred in the corning mill, which was followed by one in the press house. The corning mill was 300 ft. east of the pack house and 300 to 400 ft. southeast of the black powder magazine. The press was about the same distance east of the black powder magazine.

Fire communicated to all the other buildings and destroyed them, with the exception of another barrel type mixing house, containing 1500 lbs. of black powder in bulk. This building, located 1000 ft. from the magazine and 200 ft. from the press house, had the walls and roof crushed in, but fortunately the powder did not explode.

Based on method of operating the Works, the estimated quantity in the buildings would be—mixing house, 12,500 lbs., glaze mill 25,000 lbs., pack house, 37,500 lbs., and the press house 10,000 to 15,000 lbs. The quantity of dynamite that exploded was unknown but was estimated at 20,000 lbs., and reports of the amount of black powder in the magazine, where the largest explosion of all took place, varied, but the most reliable information indicated that this explosion, combined with the contents of the dynamite magazine, amounted 135,000 lbs.



The damage to the factory was as described above, and in addition there were two dwellings on the factory property, both of frame construction. One, 1000 to 1200 ft. from the glaze and pack house, was torn to pieces, and the woman in the house had an arm broken. The other, which was over a hill about 300 yards from the factory buildings, had the rear end torn out and the porch wrecked. A frame stable on top of the hill was also wrecked.

Of the 32 men working in the factory, 19 were killed either by the explosion or by being caught in crushed-down buildings and burned by the fire that followed. Quite a few men were injured, including the plant manager, who was quite seriously hurt, leaving the rescue work without a head and without system. Each discovery caused the crowd to flock to the spot to satisfy that human weakness of seeing all that is to be seen.

Windows were broken, plaster knocked down, and chimneys damaged for a considerable distance. The limit of broken glass was in Uniontown, about 5 miles distant.

A car containing about 4 tons of dynamite was on a siding outside of the factory enclosure, 500 ft. from the packing house, the location of the nearest explosion. The dynamite did not explode though the sides of the car were reduced to splinters.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Dwellings	None	Damaged	3300
Area of structural damage.....			3300 feet
Charted.....			1650 feet
Missiles thrown, up to.....			5/8 mile
Glass broken, up to.....			6 miles

CHICAGO, ILLINOIS

Chart No. 25

At 9.20 o'clock, on Sunday morning, August 29th, 1886, there was an explosion in a powder magazine near Chicago, Illinois. The magazine was one of a group of eight, standing on a comparatively open area of about 40 acres, about a mile and a half west of the village of Brighton, and seven miles away from the center of the city of Chicago.

The magazine was 90 feet long by 35 feet wide, constructed of brick on a limestone foundation with a slate covered roof. There were no barricades or protection of any sort between the magazine in which the explosion happened and the neighboring magazines and scattered dwellings in the vicinity.

The contents of the magazine consisted of 150,000 pounds of black blasting powder and sporting powder, and 12,000 pounds of straight dynamite; per cent strength not definitely known.

Lightning struck the magazine during a severe thunderstorm, and caused the explosion.

The brick walls of the magazine were pulverized and spread over a wide area; the limestone foundation was torn up and a large part of the material broken into small pieces, most of it being carried through the air in all directions from 600 to 1000 feet. A hole was torn in the ground, mainly tough clay, about 150 feet long, 40 feet wide, and from 10 feet to 20 feet deep.

The house nearest the explosion was on the north side of Archer Avenue, 300 feet distant. This little frame structure was torn asunder and scattered in all directions. Scarcely one board remained upon another, and the occupants were buried under the mass of ruins.

A frame dwelling, 650 feet distant, had the walls separated, and they came down with a crash, leaving only a small part of the structure standing. The walls nearest the magazine in which the powder exploded were pulled out entirely. The ceilings in the front part were loosened at one end and were left hanging by the other. That the occupants of this house escaped death was little short of a miracle.

The duPont powder magazine about 500 feet east and a little north of the Laflin and Rand magazine, had the roof wrecked and the walls cracked and sprung. This building was made of brick, 30 feet by 40 feet, with a slate roof, and contained about 40,000 pounds of black blasting and sporting powder. The damage to the contents, which were in kegs and cans, was slight, and the powder was carted away promptly after the explosion. Almost east by south, and about 500 feet distant, stood the magazine used by the Hazard Powder Company, built in exactly the same manner, and containing about the same quantity of powder. The concussion ruined the roof and wrenched the walls badly. The contents, however, were in a condition to be moved.

At a point between the two above-mentioned magazines, but directly across the road from the magazine, the contents of which exploded, stood a little shanty. It was simply a frame box containing two rooms, and a woman lived there alone. It was completely wiped from the face of the earth, and a mass of rubbish, timber and furniture was spread among a few bushes that formerly flourished about the little cottage. Not a stick was standing upon another, and the bedding and furniture was scattered and twisted in a most fantastic manner.

Within a radius of 600 feet there were five other magazines, all of which had the roofs crushed in and the walls badly damaged.

About 1200 feet from the scene of the explosion were two small frame

dwellings and outhouses, all of which suffered severe structural damage, and were struck by missiles (stones from the foundations). The large families that occupied these houses suffered but slight injuries, principally from flying glass. The interiors of the houses were wrecked.

Beyond 1200 feet, and up to 3000 feet, there were a number of small frame buildings. The damage to them dwindled from the breaking of rafters and supports to the pulling out of doors, window sash, etc., and the limit of structural damage can be placed within the 3000 foot zone.

As a result of the explosion, two women were killed within 300 feet, by being caught in the wreckage of demolished houses. A farmer driving past in his wagon immediately in front of the magazine when the powder exploded was found to be so frightfully injured that he died later. One of the horses attached to the wagon was killed outright, and hurled with the wrecked wagon into a ditch by the side of the road. The other animal was badly hurt, but tore loose from the harness and was able to run away from the scene. Two men and one woman, who were in dwellings within 600 feet of the explosion, received quite serious injuries from flying debris. The injuries consisted of broken bones and severe cuts.

The missiles, which consisted of stones from the magazine foundations, did considerable damage and injured a number of people, principally within 1200 feet of the explosion, although some missiles were thrown to a distance of half a mile.

The glass breakage was considerable, and numerous slight injuries resulted from persons being cut by pieces of broken window glass. This class of damage extended as far as the center of Chicago, about seven miles away.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Area of structural damage.....			3000 feet
Charted.....			1500 feet
Missiles thrown, up to.....			$\frac{5}{8}$ mile
Glass broken, up to.....			7 miles

BRESCIA, ITALY

Chart No. 19

There was an explosion at Brescia, Italy, in the year 1769. The explosion occurred in a square tower 70 feet high, and 18 feet in diameter, outside measure. The walls of this tower were 5 feet thick. It was two stories high, and entirely above ground.

The amount of explosives involved in this explosion was about 175,000 pounds of gunpowder.

In regard to the damage done by this explosion, it was reported that within a radius of 639 feet, 190 houses were destroyed. Within a radius of 1917 yards, 500 houses were greatly injured.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
500 houses		Greatly injured	1917
	Area of structural damage		1917 feet
	Charted at		958 feet

VIENNA, AUSTRIA

Chart No. 176

There was an explosion in a powder magazine near Vienna, Austria, on June 7th, 1912. A translation of an authentic report was made, as follows:

"The powder magazine where the explosion occurred, at 8.21 A. M. on June 7th, 1912, was situated on the western border of the aviation ground near Wiener-Neustadt.

At the time of the explosion there was 150,084 kilos of smokeless powder, 5867 kilos of black powder and about 100 8-centimeter cartridges for trial purposes in this magazine," (making a total of approximately 342,190 pounds of explosives in addition to the cartridges).

"The cause of the explosion could not be ascertained, but it is certain that it was not due to the deterioration of the powder.

There was only an artificial protection around the magazine in the direction of Wiener-Neustadt, at a distance of 160 to 200 feet from the magazine, namely, an abandoned earthwork.

The magazine was a solid brick building with groundfloor only; the double timbers of the roof were covered with slate. The building was surrounded by brick pillars and a wooden fence.

Nearly all the windows of the buildings of the ammunition factory at Wellerdorf, situated at a distance of about 3500 to 7000 feet from the explosion, were smashed. A great part of the window casements and leaves (panels) of doors were torn out and damaged; also part of the iron shutters were bent.

The roofs of buildings consisting of tiles or concrete plates were partly blown off and destroyed. A great number of rafters of structures, situated

up to a distance of 3600 feet from the magazine, were crushed and broken, and in some cases the roofs were lifted, and permanent gapings were produced.

In some structures with lath and plaster walls, the posts were cracked and the brickwork loosened.

Examination of about 400 buildings in the city and suburbs of Wiener-Neustadt led to the discovery of very slight damage.

The sheds on the aviation ground (distance about 2689 feet) some workmen's huts (distance about 5000 to 6500 feet) and the artillery barracks were considerably damaged.

Mostly those buildings in the city and the suburbs at distances from about 6500 to 14,700 feet which were high or detached, or in the direction of the prevailing wind, were damaged.

The damage done on the aviation ground consisted in blown-off roofs, crushed in lath and plaster walls, broken rafters, window casements and door posts. In the artillery barracks and workmen's huts, many window casements and door leaves (panels) were broken, the roofs were damaged, and most of the windows smashed.

At the time of the explosion, there was a military clerk and five civilian workmen in the magazine, all of whom were killed. Two other civilian workmen, standing between the inner room of the magazine and the automobile, by timely flight saved their lives, but sustained numerous serious injuries.

Two gunners employed as chauffeurs, and the civilian guard of the automobile truck, standing near the automobile were likewise killed.

Regarding the nature of the injuries, the following was ascertained:

The military clerk was so completely torn to pieces that his remains could not be identified.

The death of the other men was partly caused by the pressure of air, and partly by debris flung about. Also the above-mentioned workmen were injured in this way.

A one-year volunteer who was standing near the wash-house, 400 feet away from the explosion, was seriously injured on the head by a piece of iron, and succumbed several days afterwards.

Of the soldiers forming the guard of the powder magazine, four men were knocked down and more or less seriously injured.

In the various workshops, offices and dwellings of the ammunition factory, altogether over more than 100 civil and military persons were more or less injured, mostly by glass splinters.

Even there, at a distance of 3280 feet, the pressure of air inside the buildings knocked several persons to the ground."

It was estimated that structural damage extended as far as 4440 feet.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion	
Ammunition factory	Artificial	Casements, doors smashed	3444 to 7216	
Houses		Rafters broken, roofs lifted	3608	
Aviation sheds		Roofs off, plaster walls crushed, rafters broken	2689	
Workmen's huts		Roofs damaged, casements broken	4920 to 6560	
Buildings		Damaged slightly	6560 to 14,760	
Area of structural damage			4440 feet	
Charted			2220 feet	
Missiles thrown, up to			No record	
Glass broken, up to			No record	

HIGHLAND STATION, CALIFORNIA

Chart No. 58

An explosion involving a tremendous amount of powder occurred at the Giant Powder Works at Highland Station, near Berkeley, California, on July 9th, 1892, at 9.23 A. M.

There were five separate explosions, beginning with a small detonation in the nitroglycerin house, and involving the nitroglycerin wash house, dynamite mixing house, box packing house and two magazines, one containing dynamite and the other Judson and black powder.

The magazines had brick walls 15 inches thick, and roofs of closely laid solid timber, covered with metal. They were barricaded.

A narrow ridge having two summits extends about 900 feet from north to south along the eastern shore of San Francisco Bay, forming an obtuse point about 7 or 8 miles from the city. The northern summit was about 100 feet and the southern summit about 80 feet above the water, with a depression between them about 60 feet above sea-level. On the northern slope of the higher hill at a height of about 80 feet stood the nitroglycerin factory where the explosion originated. The five buildings in which the explosions occurred stood at the foot of the northern hill at a point about 20 or 30 feet above the water, extending in a general direction east and west. These buildings were individually separated from each other by earthen traverses.

The initial explosion in the nitroglycerin house was a small affair, merely the remnants of nitroglycerin and acid left in the two separators. This explosion killed the three white men in the house, and flung their bodies into the bay which lapped the foundation of the building. Had it not been for the open trough running with the remnants of the nitroglycerin and acid

into the wash tanks some 60 feet away, each trough containing a run of about 2000 pounds of nitroglycerin, the original explosion would have done very little damage. The building itself was so little damaged that the engineer in charge of the compressor machinery, about 250 feet away, although he heard and felt the shock, and knew that an explosion had taken place, only noticed the end wall of the building, facing the bay, torn apart.

Immediately afterwards the contents of the wash house exploded, the nitroglycerin in the wash tanks having been detonated by the various explosions occurring in the trough leading into them. This second explosion practically destroyed all the buildings on that side of the hill; the boiler and compressor house, gelatin house, recovery plant and concentrating buildings, and store houses on the two wharves, some 2000 feet away. All these buildings were in a direct line with the wash house, with no obstruction between.

Some burning embers set fire to the contents of one storehouse on the wharf, igniting the sulphur in it, and fire was communicated to the mixing house, which with the two small packing houses adjoining it, made the third separate explosion.

Fire was also communicated to the roof of a large substantial building, where powder boxes were nailed up as they were brought from the packing houses; this building contained some 400 or 500 boxes of dynamite which exploded, making the fourth separate explosion.

It was this explosion which crushed in the roofs of the two large magazines, some 120 feet away, set fire to explosive contents and caused them to explode with terrific effect, 4 minutes and 40 seconds after the original explosion. Both magazines were pretty well stocked, one with dynamite and the other with Judson and black powder. Only a deep hole, some 50 feet in diameter and 22 feet deep, showed the places where the buildings had stood.

A small magazine some 20 feet farther away, containing some odd boxes of blasting gelatin, was literally crushed and flattened from falling brick, etc., but the contents did not explode.

The explosion in the magazines did all the damage in the surrounding neighborhood, and even in San Francisco, 8 to 10 miles away.

A man testified that he was running past the magazines after the first explosion in the nitroglycerin house, and saw the magazine doors open, and closed them. It is supposed that the magazines were set off by fire, and if the roofs were crushed, or doors open, sparks might have done the business. In view of the interval of time, this account does not seem improbable.

The total quantity of explosives involved amounted to 398,415 pounds; 207,065 pounds of dynamite, 176,500 pounds of Judson, and 14,850 pounds of black powder.

The original cause of the explosion was never known. There were 5

men killed, and 20 injured. Two men driving in a buggy from Highland Station reached a point about 1000 feet from the magazines when the first explosion occurred in the nitroglycerin house, followed by the wash and mixing houses. They stopped, and then not expecting more explosions were about to pursue their way, when the box packing house, next to the two magazines, went up. The shock from this explosion toppled the buggy over and both men were on the ground when the magazines were exploded. The fact that they were on the ground partly covered by the buggy, undoubtedly greatly minimized the effect of the last explosion on them, and although close to an explosion of such magnitude, they escaped uninjured. There was no danger of their being hit by flying bricks from the magazines, for they were all finely pulverized, not one piece of any brick having been found.

The structural damage was partly due to fire and partly to explosion. At the works proper, the buildings, inside of a radius of 1500 feet, which were large substantial structures like the acid chambers, boiler houses, storehouses, etc., were badly crushed although they were protected from the direct shock by a hill 35 feet high, besides the embankments surrounding the magazines, which were 5 feet higher than the roofs.

The stables and boarding house of the company, and some buildings belonging to a chemical company and used for sulphur grinding, had their roofs partly crushed, but were otherwise not seriously damaged. These buildings were about 2500 feet away.

Protected by the hill and about 2500 feet away was a chemical works, which, being old and rather flimsily constructed, completely collapsed. The Giant Powder Company's machine buildings, dry houses, nitre storehouses, etc., suffered little outside of crushed-in roofs. Two dwellings at the same distance, 2500 feet, had their roofs crushed in, whether by lifting and falling, or by direct pressure, is not clear. One wall nearest the explosion was sucked out, but the houses were otherwise in a fair state of preservation.

In West Berkeley, between 2 and 4 miles away, some windows were broken, some doors torn from the hinges, and plaster down everywhere. In East and North Berkeley, about 5 or 6 miles away, the same sort of damage happened on a smaller scale.

Some Chinamen's houses and stables, light shanties, at about 4000 feet, were all badly shaken.

On the ridge in the depression between the two hills, and protected by the northern one, was a brick house about 500 feet away. It was unroofed, and its gables shaken off for a few feet. On the top of the lesser hill was a high brick chimney, which was badly shaken and cracked.

No great destruction was done beyond a quarter of a mile.

A good many pieces of twisted iron pipe were thrown as far as $1\frac{1}{2}$ miles away.

The greatest glass breakage was in San Francisco, 10 miles across the bay.

At the time of the explosion a very slight wind was blowing from the southeast.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Machine house	Hills	Roof crushed, wall damaged	2500
Area of structural damage			2500 feet
Charted			2500 feet
Missiles thrown, up to			1½ miles
Glass broken, up to			10 miles

ROME, ITALY

Chart No. 85

A tremendous explosion occurred at Vigna Pia, about 3 miles from the center of the city of Rome, in a powder magazine outside of the Porta Portese, at 6.38 A. M. on April 23rd, 1891.

The magazine measured about 48 by 18 feet, and was massively constructed of travertine, an Italian yellow limestone. It was a single structure two stories high, with a basement and attics. One story was used for a pyrotechnical laboratory, and the other was used as a storage magazine. The building was located at the bottom of a small valley, called Pozzo Pantaleo, surrounded by little hills. It adjoined the Vigna Pia, the model farm started by Pope Pius IX.

The magazine enclosure was surrounded by a wall and a ditch, but the magazine was not barricaded. Two sentinels paced the enclosure. The entrance to the magazine was always carefully guarded, and nobody but the soldiers of the guard and the operators in the laboratory were allowed to enter.

The magazine contained about 570,000 pounds of black powder, an unusually large amount, and in addition there were 24,000 cannon cartridges, besides quantities of various combustible stores, such as fuses, detonators, friction tubes and fireworks. No nitro compounds were present.

At 3 o'clock on April 22nd, the day before the accident, the laboratory was closed, and the custody of the building was left as usual in the hands of the guard, a detachment from the 12th Bersaglieri Regiment.

Nothing unusual occurred during the night, but at 6.20 A. M. the sentinel heard a report like a subterranean explosion. He informed the corporal, who informed a lieutenant in the fort nearby. The lieutenant and another

man immediately ran to the magazine, joined by a captain, who had also heard the explosion and believed that it might have been caused by the detonation of some cartridges. They attempted to enter the magazine, but found the keys were in the hands of the custodian of the fort, who was away.

Seeing that there was no time to be lost, the captain ordered the guard to leave and took active measures to warn people in the vicinity to leave their houses and escape. In about 18 minutes, the terrific explosion took place, leaving no trace of the magazine but a 300 foot crater.

The magazine had been surrounded by rich vineyards, which were all destroyed. Stones, bricks, and large pieces of timber were thrown to great distances. The captain was about 300 yards away from the magazine at the time of the explosion. He was wounded in the head and chest by a large stone, which threw him to the ground and knocked him senseless. The corporal who gave the alarm was wounded so seriously in the leg that it had to be amputated.

Owing to the presence of mind of the captain, the results of the explosion were less disastrous than they might have been. Only 4 men were killed. Among them was a priest from the Vigna Pia, the model farm owned by the church and worked by 200 boys. Fortunately none of the boys were seriously hurt, though 20 were slightly injured. More people were hurt at a distance from the explosion, in Rome, by collapsing houses and especially by broken glass, than were hurt on the spot. The figures are given as 170 injured in Rome and 44 in the vicinity.

King Humbert, accompanied by the Duke of Abruzzi, came from Rome to the scene of the disaster to help in the relief work, and was followed by an immense crowd. Amid great enthusiasm and applause the injured captain was borne away in the royal carriage.

Great damage was done in Rome. Not a pane of glass remained unbroken in the Capitoline. In the Quirinal, the glass in all the windows and most of the mirrors were broken. The same damage was done in the Vatican; the glass of the Gallery and the Loggias, the painted glass in the Library and in the Museum, the plate glass in the Royal Staircase, which was a present from the King of Bavaria, was all broken. In St. Peter's, the great painting on glass representing the Eternal Father was broken, and the glass in the cupola was smashed. In St. Paul's, mosaic and glass were broken.

Serious structural damage was done to buildings at a distance of 2625 feet. Roofs and interior partition walls were badly damaged up to 4950 feet, in three instances, and a window built up with masonry was blown in at a distance of 15,000 feet.

Broken glass was general throughout the city. At a distance of 21,000 feet, 61 panes were broken.

This explosion was recorded by the seismograph like an earthquake shock, showing three distinct earthwaves.

SUMMARY

Building damaged	Barricaded	Extent of damage	Feet distant from explosion
Roofs and walls in 3 instances	No protection	Badly damaged	4950
Area of structural damage.....			4950 feet
Charted at.....			2625 feet
Missiles thrown.....			No record
Glass broken, up to.....			21,000 feet

BALTIMORE, MARYLAND

Chart No. 177

The British tramp steamer "Alum Chine" was destroyed by an explosion on March 7th, 1913, at 10.40 A. M., while taking on a cargo of dynamite in the Patapsco River about six miles southeast of Baltimore, Maryland.

The "Alum Chine" was 267 feet long by 35 feet beam, and was 1120 registered tonnage. She was anchored well clear of the main channel at the lower end of what was known as "Quarantine Slip." A cargo of 2200 tons of bituminous coal had already been loaded into the holds of the vessel, and 600,000 pounds of dynamite was being loaded on top of the coal in the forward hold only.

The explosives, consisting of 7000 cases of 45% and 5000 cases of 60% Straight Dynamite, was destined for construction of the Panama Canal. It had been shipped from Emporium, Pennsylvania, in ten cars of 60,000 pounds each on the Pennsylvania Railroad, and had been packed, loaded and shipped in accordance with the regulations of the Interstate Commerce Commission in regard to the shipment of explosives. The cars were held at Bay View, just northeast of Baltimore, until they could be brought through the city directly onto the car floats.

On March 6th the ten cars were taken to the vessel on two car floats, and the loading commenced. Heavy weather broke one car float loose from the vessel, and the tug in charge was unable to handle it alone and had to get outside assistance. Seven cars were loaded on the ship that day. The car float with the remaining three loaded cars and one empty car aboard was then taken back to the slip to wait for more favorable weather. The unloading of these cars commenced again on the morning of the 7th, and was nearly completed when the accident occurred. The testimony of the

second officer of the "Alum Chine" and one of the stevedores, indicated that there were between 300 and 400 cases on the car float yet to be transferred at the time of the explosion.

The cases of dynamite were handled by chutes from the cars into the hold of the vessel. The "Alum Chine" was heavily loaded and low in the water. The chutes were blocked up at the cars, which permitted a slight grade over the rail to the top of the hatch, but the cases did not slide entirely by gravity and had to be helped along. Another chute stretched from the top of the hatch to the loading point in the hold, at a steep enough grade for the cases to run by gravity.

The vessel was known to be on fire fifteen or twenty minutes before it was destroyed, a sufficient interval to give the stevedores and the crew a chance to escape.

It was known that the explosion was caused by fire, but the origin of the fire was never determined. Effort was made to prove that it was the result of a minor explosion of one case of dynamite, set off by the act of a stevedore in using a steel hook. An equal number of witnesses testified that fire originated in the hold, forward of the dynamite.

The casualties reached 31 killed, and 38 injured. The deaths and serious injuries were limited to those directly interested in the loading of the vessel, either as stevedores or crews, with the exception of the men on the U. S. Collier "Jason," which lay at anchor nearby.

The serious structural damage was limited to the "Alum Chine", the car float, the tug "Atlantic", the U. S. Collier "Jason", and the works of a chemical company at Hawkins Point.

The forward portion of the "Alum Chine" above the water line was destroyed, the largest piece found being a steel plate about 4 feet long and 2 feet wide. The portion of the vessel below the water was sunk in one section. A diver sent down found the rim of the hull spread and the edges of the steel plates so jagged that the diver did not approach the hull on account of risk of damage to air and life lines. The explosives were in the bow of the vessel, which was headed northwest. Evidence showed that the majority of the missiles were thrown northeast and southwest, at right angles to the wind.

In escaping from the "Alum Chine" the men ran out over the car float alongside and onto the tug "Atlantic". The "Atlantic" left with all that appeared to be on board, but later two men ran from the "Alum Chine" onto the float. These men probably cut the car float loose as a last resort, as the float was reported to be 50 to 75 feet distant from the "Alum Chine" when the explosion occurred. The hull of the float was recovered, badly wrecked.

The tug "Atlantic" took on 35 men and was leaving the scene when the

two men on the car float called for help. The tug returned, picked up the men and had reached a distance of between 600 and 700 feet away when the explosion occurred. The heaviest loss of life developed on the decks of the "Atlantic". Her pilot house was torn away and the super-structure was badly wrecked, both by the concussion and by missiles. Fire was blown from under her boiler, and when the tugs "Reihl", "Brittania", and fire boat "Lannon" arrived, she was on fire. The "Reihl" took off the injured, being the first to reach her. The "Lannon" took off the dead and tried to put out the fire. The "Atlantic" sank before reaching shoal water, due partly to her damaged condition, but mainly to the water pumped into the hull by the fire boat.

Of the 35 men on the "Atlantic", 9 were killed outright, 15 seriously injured, and the remainder only scratched and jarred, many of them not actually injured at all.

The U. S. Collier "Jason" was a steel vessel 536 feet long, 65 feet beam by about 35 foot draft. She was lying between 1200 feet to 1500 feet from the "Alum Chine", head to the wind, northwest. The captain of the "Jason" was aware of the fire on the "Alum Chine", knew the nature of the cargo, and attempted to get up anchor and get away, but was caught before succeeding in doing so. Six men were killed on her decks, and about 15 injured. Most of the damage to the "Jason" was done by missiles. The largest hole in her hull was about 12 inches in diameter. All the brass casings of the portholes were blown in, the wireless room was wrecked, and all loose furnishings and light structures were damaged. A ventilator was thrown 50 feet from its position. Many deck supporting columns were bent from 2 to 6 inches out of line, showing a sag in the deck, which indicated serious structural damage from concussion, as well as from missiles.

The launch "Jerome", 450 feet distant from the explosion, escaped with only broken glass and sash. The tug "Reihl", from 1500 to 2000 feet distant, suffered damage only to glass, sash and doors.

Fort Carroll, 2500 feet from the explosion, and Fort Armistead, 2100 to 2500 feet away, suffered no material damage.

A sulphuric acid plant at Hawkins Point showed very serious structural damage. The large lead chamber shed, 3000 feet from the explosion and unprotected, was badly damaged by concussion and by missiles. The walls were shattered and a lead chamber caved in. Another building of like nature 3200 feet from the explosion, was pushed out of plumb from one to two feet. A brick retort house had timbers broken and the roof caved in. This plant was old and weakened from effects of acid fumes.

The dwelling quarters of the workmen suffered no material damage, except for doors, windows, fences and plaster badly wrecked.

No damage was done to the Quarantine Station, at a distance of 5800 feet.

The extreme radius of glass damage was at the Bay View Asylum, at a distance of $5\frac{1}{4}$ miles.

Missiles were thrown from 2 to 3 miles.

SUMMARY

Building damaged	Protected	Extent of damage	Feet distant from explosion
Building on the Chemical Company Plant	No	Pushed out of plumb $1\frac{1}{2}$ feet	3200
Area of structural damage.....			3200 feet
Charted.....			1600 feet
Missiles thrown, up to.....			2 to 3 miles
Glass broken, up to.....			$5\frac{1}{4}$ miles

FONTANET, INDIANA

Chart No. 45

On Tuesday morning, October 15th, 1907, at about 9.15, a disastrous explosion occurred at the black powder works at Fontanet, Indiana. The entire plant, with the exception of two corning mills, one press, and two wheel mills, was destroyed.

The explosion started in the glaze, which set off almost simultaneously the pack house and black powder magazine holding approximately 35,000 kegs, or 875,000 pounds, of black powder.

When the magazine blew, powder burning in the air covered the plant with a veritable shower of fire, and accounts for the rapid destruction of all the other mills. Fire subsequently raged, and great loss of life resulted.

The dynamite magazine, containing about 19,000 pounds, did not blow until nearly an hour after the other explosions. This magazine was on fire and burned for some time, possibly an hour after the black powder explosion, before the blowing up of the contents. No additional destruction of property or loss of life resulted through this explosion.

It is probable that the missiles which set off the pack house and the magazine at practically the same moment must have struck the magazine in a number of different places; otherwise, so complete an explosion of all powder in the magazine would not have occurred. This theory is based upon a knowledge of previous explosions, where magazines firing at a particular point resulted in the explosion scattering over a considerable area kegs filled with powder, which detonated when the kegs struck the ground.

The scattering of fire and the rapid destruction of all other buildings but the two corning mills, and the demolition of the town was due largely, if not wholly, to the terrific force of the magazine explosion.

Considering the completeness of the destruction, the limited number of casualties was surprising. It is a remarkable fact that outside of the mill premises no one was killed. The force of the magazine explosion and destruction of buildings on the plant buried many employees who were working in non-explosive buildings. Burning soda scattered over the plant caused a fire which made the devastation complete, and cremated many of the imprisoned unfortunates.

The black powder magazine was located in a ravine, with bluffs on three sides. The most distant damage in every instance occurred on the side of the magazine that was not barricaded or screened by the bluffs. There were 500 buildings in the vicinity of the explosion, of which about 80% were one-and-a-half story frame dwellings. The balance consisted of frame structures on coal-mine properties, church, schoolhouses, etc.

All buildings within a radius of 1500 feet were practically demolished. In some cases, this serious class of damage occurred at a point as far distant as 2600 feet. Substantial structural damage was experienced up to a distance of 4000 feet, but within this zone there were numerous structures which suffered more or less minor damage.

There were 24 persons killed, all of whom were within the plant area and within the 1000 foot zone. Eleven persons were permanently injured, 9 disfigured, and 23 suffered minor injuries. These latter were within a zone of about 2000 feet.

There was general glass breakage at a distance of 4 miles.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Three houses	See note	Rafters broken, glass, plaster and chimney broken	4000
Area of structural damage.....			4000 feet
Charted.....			2000 feet
Missiles thrown.....			No record
Glass broken, up to.....			4 miles
NOTE:—In the section where the bluffs afforded protection, the area of structural damage was half of the distance where this protection did not exist.			

ARDEER, SCOTLAND

An explosion occurred in the Explosives Works at Ardeer, Scotland on March 10th, 1913, at 11.10 A. M.

The explosion took place in four gun cotton stoves or drying houses, numbered S445, S447, S454, and S456, each in two compartments. Each building measured 100 feet by 30 feet, and was divided into two compartments by a central partition. The walls were of wood and the roof of corrugated iron, lined throughout with canvas, and the floor was wood covered with linoleum.

In each compartment were eight racks on which the guncotton primers were placed for drying. The framework of these racks was made of galvanized iron tubes connected by horizontal wires of brass. At all points where the wires passed through the tubes the holes were countersunk and filled up flush with solder. Eight shelves were thus provided one above the other, and at each end the tubular frame was extended and carried across to stiffen the rack.

There was one double door to each compartment opening to a platform, and this platform, together with the wooden tramrails by which the material was brought to and removed from the building, was protected from the weather by a light roof. Each building was surrounded on all sides by very substantial mounds of sand, revetted almost entirely with sheets of corrugated iron secured in position by stout wooden tie-baulks.

The heating was effected by air driven by fans through a casing 4 feet 6 inches in diameter containing a series of pipes through which steam was passed. The hot air was distributed through each compartment by means of a conduit 15 inches square running around three sides of the building, with inlets at intervals covered with wire gauze. The temperature while drying was in progress was kept at about 110° Fahrenheit.

At the time of the accident, the conditions in the four drying houses were as follows:

S445. Compartment A contained 6,000 pounds of guncotton, which had been drying for 89 hours, and the hot air blast had been reduced in expectation of its discharge next day. The temperature was taken shortly before the accident and registered 107°F. at the inlet and 105° inside the compartment. Compartment B was in course of discharge by two of the employees, a third employee being also present on the porch. The air blast to this compartment had been cut off at 5.30 A. M. and the work of unloading begun at 7.45 A. M. About 2,500 pounds of dry guncotton had been removed and 2,000 pounds of wet primers in aluminum boxes holding between 30 and 40 pounds, were standing on the shelf outside the door of the compartment. Two men were waiting outside the mound just clear of the entrance passage.

S456. Compartment A contained the full quantity of 6,000 pounds, not due for discharge until the 12th. The temperature was 125° at the inlet and 107° outside. Compartment B contained 2,000 pounds of dry guncotton

and 2,000 pounds of wet in boxes on the porch ready to be put on the racks. The heat had been cut off at 5.30 A. M. and the unloading commenced at 7.45 A. M. Two men were engaged in this work.

S447 and S454. Each of these drying houses contained the full quantity allowed, 6,000 in each compartment. The blast was on in S454, but in S447 the blast had been cut off for repairs to the engine, and the building was cold. No one was present in either of these buildings.

At the time of the explosion, the quantity of dry guncotton in the four drying houses was as follows:

In S445.....	9,500 pounds
In S456.....	8,000 “
In S447.....	12,000 “
In S454.....	12,000 “
<hr/>	
Total.....	41,500 “

The explosion originated in building S445, and was communicated to the other three buildings, whose contents exploded one after the other. The first explosion took place at 11.10 A. M. Seven men were killed, nine were slightly injured and two severely injured. The two employees in S445, the man on the porch, and one of the two men waiting just outside the mound were killed, the second man escaped with slight injuries. Of the two men who were engaged in repairing the engine of S447, one was killed, the other injured slightly, and the engineman also received slight injuries. The two employees in S456 were killed. The other eight men who were injured were working on the plant at distances varying up to 300 feet.

The effects of the explosion were severe, the four drying houses being completely destroyed, and no portion of any of them left intact. The barricades of S445 and S447 were of the plate bank type, and were entirely demolished. The barricades of the other two buildings, consisting partly of sand banks, were not so badly damaged.

In view of the elaborate precautions taken to avoid accident, it was hard to suggest a probable cause for the explosion. From the appearance of the craters, it was thought that either the gun cotton in bags near the stove, or that which remained on a rack, exploded. In all probability the two stovemen were removing primers from the rack, and some act of theirs may have caused the accident. The wooden stand that held the canvas bags of guncotton might have been dragged over the floor, and the friction thus produced might have caused the explosion.

The drying houses were situated on the northeast part of the plant on low ground near the River Garnock. Three cordite drying stoves, the acetone still house, the boiler and engine houses of the No. 3 nitroglycerin

factory, and the mess rooms for men and women suffered severe damage. The direction of the wind was almost due west, away from the factory, and owing to this fortunate fact, only the plant buildings in the immediate vicinity were badly injured.

The wind was blowing toward the town of Irvine, across the river, and the damage to windows and ceilings there was extensive, with a few cases of cracked walls and damaged roofs. Similar damage was reported at Kilmarnock, and from isolated farms and houses in the surrounding country.

Careful consideration of the results of the explosion gave the following distances for structural damage:

300-600 feet. Within this area buildings were totally destroyed, walls and roofs collapsed.

600-1200 feet. Within this area walls and roofs were displaced, walls and house shifted.

1200-1800 feet. Within this area, walls and sides displaced, roofs, walls, and woodwork damaged.

Beyond 1800 feet. Slight damage only, roofs somewhat displaced, windows and glass broken.

Debris, consisting of splintered wood and small portions of the iron racks, was projected with the wind toward the river. Some pieces went to considerable distances even against the wind, and one piece of iron was found in the floor of the Cordite Incorporating House, 1572 feet from the site of the explosion.

Glass was broken at a distance of 3600 feet.

SUMMARY

Building damaged	Barricaded	Extent of damage	Feet distant from explosion
Building	Artificial	House and engine house displaced and damaged	1800
Area of structural damage.			1800 feet
Glass broken, up to.			3600 feet
Missiles thrown, in one instance.			1572 feet

BATUCO, CHILE

At 5.55 P. M. on March 23rd, 1908, an explosion occurred among the powder magazines of the Chilian government at Batuco, 18 miles north of Santiago.

The four magazines were placed close together, at distances from 120 to 240 feet apart, on an almost level plain. The ground was thinly covered with pine brush, and surrounded on three sides by high hills.

The magazines were built in 1896, and conformed to the general type in use at that period. They were equal in size and construction. The base was 69 feet long by 63 feet wide. The walls were built of wood, and double, the roof was made of galvanized corrugated iron, provided with lightning rods in contact with it.

Most of the powder was stored in zinc-lined boxes. A small part of the black powder was in copper and part of the smokeless was in cylindrical zinc barrels with wooden staves. All boxes and barrels were hermetically sealed, piled nearly to the roof, separated by wooden laths.

Magazine No. 1 contained over 2000 boxes and was absolutely full, having received 10 additional tons of black powder 8 days before the explosion. It was not provided with forced ventilation. It was in this magazine that the original explosion took place, and was communicated to Magazine No. 2. These two buildings contained 170 tons of black powder, 3 tons of dynamite, and 3 or 4 tons of smokeless powder stored together, a total amount of explosives estimated at 352,000 pounds.

The contents of Magazine No. 3, smokeless infantry ammunition and chilenite (picric acid) did not explode. Magazine No. 4 was empty. These two buildings were, however, completely demolished by the explosions in the other magazines.

On the site of Magazines No. 1 and No. 2, conical holes 150 feet in diameter and 60 feet deep were formed. Only a few blocks of the magazine foundations remained.

In regard to the cause of this explosion, a board named by the Chilean Minister to investigate, found that though the smokeless powder was 13 years old, it showed no signs of deterioration, and gave the cause of the accident as spontaneous decomposition from faulty storing. An expert in the Chilean army claimed that the cause of the explosion was static electricity due to the sudden alteration in the electric state of the atmosphere at sunset, when the explosion happened.

There was no information as to the number of killed and injured, and the distances at which buildings were damaged, but this explosion is interesting on account of the large quantity of explosive involved, and the reasons advanced for the cause of the explosion.

BEIRA, PORTUGAL

During the siege of Almeida by the French in the Peninsular War, there was an explosion in a powder magazine containing 165,000 pounds of explosive, at Beira, Portugal.

The cathedral, 540 feet from the explosion, and three-quarters of the town, which lay within a radius of 660 feet was destroyed. Large masses of stone were thrown into the French trenches, about 2650 feet away.

BLACK TOM ISLAND, NEW YORK HARBOR

Two serious explosions in munition supplies intended for export occurred at Black Tom Island, New York Harbor, on Sunday morning, July 30th, 1916. The first explosion was 100,000 pounds of picric acid in a barge lying in the open river about 300 feet northeast of North Pier, and the other involved 400,000 pounds of T.N.T. in eight cars in the freight yard at the west end of North Pier.

Black Tom is situated on the western shore of the Upper Bay, New York Harbor. Originally an island, the space between it and the Jersey Shore was filled in, so that it joined the mainland. The property was about 4000 feet long and 1400 feet wide.

Black Tom was occupied by the warehouses of the National Storage Company, and the offices, docks, float bridges and tracks of the Lehigh Valley Railroad. The tracks were used for the storage of cars containing merchandise awaiting delivery to consignees, or unloading into warehouses nearby. At the eastern end of the property was North Pier, 500 feet long, used by the railroad company when shipments of munitions were to be transferred from freight cars to barges.

When the barges were loaded with munitions, they were generally taken down the bay at once and their cargoes transferred to vessels anchored off Gravesend, the designated Government anchorage; but if the foreign vessels did not arrive on time, or if there was some other reason for delay, the lighterage companies permitted their barges either fully or partially loaded to remain in the vicinity of North Pier for several days. On the night of the explosion, there were ten barges at the pier.

At 6 P. M. on July 29th, there were seventeen cars containing explosives on the railroad company's tracks, and on North Pier. There were also eleven cars of dry T.N.T., packed in wooden cases, a total of 550,000 pounds. Eight of these cars, containing 400,000 pounds, were located on track 16. On track 18, extending to the end of North Pier, were the other three cars of T.N.T., two carloads of munitions, and four empty cars just unloaded. Three cars of wet nitrocellulose, and a car of 4,200 time fuzes on track 16, were coupled to the eight cars of T.N.T. mentioned above. The wet nitrocellulose did not explode.

The total amount of explosives on the tracks at the time of the explosion was 550,000 pounds of T.N.T., 90,865 pounds of wet nitrocellulose, 25,200

pounds of T.N.T. in shell and cartridges, 6,415 pounds of black powder, and 53,437 pounds of smokeless powder. There were also three cars on the tracks containing chlor-benzol in metal drums, a liquid with a flash point of approximately 90°F.

In the ten barges tied up to North Pier or in the immediate vicinity were the following quantities of explosives: 350,500 pounds of T.N.T., 100,000 pounds of picric acid, 25,000 detonating fuzes, 1,397,160 pounds of black and smokeless powder, 878,700 pounds of wet nitrocellulose, and in shell and cartridges 124,082 pounds of black and smokeless powder, and 31,000 pounds of T.N.T.

At about 12.50 midnight a watchman noticed a fire in the yard to the west. With three other watchmen and the captain of one of the barges he started towards the warehouses; discovered one of the freight cars on fire, and sent in an alarm. The fire departments responded, and the night yardman with a crew attempted to move away some of the cars of explosives to the south. By this time shell and shrapnel were exploding, fragments falling all about, and no directed effort could be made to extinguish the fire. Not far from the place where the fire started were the three cars containing the chlor-benzol in metal drums, and their contents increased the volume and intensity of the fire. Tugs arrived at about 1.30 A.M., and attempted to pull away the ammunition barges. Some were cut loose, others burned loose and drifted away from the pier. The railroad employees were still switching and coupling cars when the first explosion occurred, at 2.08 A. M.

Barge No. 17, loaded with 100,000 pounds of picric acid and 25,000 detonators was on fire, and had drifted burning to a point about 300 feet northeast of the pier, when its contents exploded. The exact place where the explosion happened was ascertained afterwards by soundings, showing the depression in the bed of the harbor.

The explosion was extremely violent. Immediately afterwards the warehouse walls were heard to fall, cars were broken apart, and fire was distributed all over the yard, to the warehouses and the barges.

The work of the switch crews was disorganized. All the men tried to leave the yards with the exception of the night yardmaster and one switch crew, who still proceeded with the work of shifting cars.

At 2.40 A. M. the second explosion occurred, the 400,000 pounds of T.N.T. in the 8 cars on track 16. A crater was formed 375 feet long by 175 feet wide and from 7 to 10 feet deep on the line where the cars had stood. The ground where this crater was formed was filled-in land, and was therefore comparatively soft. The crater was considered very shallow indeed for such a quantity of explosives. Had the 400,000 pounds of T.N.T. been piled together in a magazine, it would have made a crater at least three times as deep. The space between the cars and the ground, more than four feet,

gave it a more severe lateral effect. This explosion was not as sharp as the first although a larger quantity of explosives was involved. Part of the 400,000 pounds of T.N.T. on the freight cars burned without exploding.

As a result of the two explosions, four men were killed on the island, and many injured. In Jersey City a baby was thrown from a bed and killed. More injuries due to broken glass might have occurred had the explosions occurred in the daytime, when people were on the street or at work.

The warehouses, 1220 feet away, had their roofs lifted and upper walls shattered by the force of the first explosion and were completely wrecked by the second. Of the freight cars in the yards, 161 were totally destroyed and 108 badly damaged. There was some minor structural damage, consisting of doors torn loose, windows and sash blown in, etc., in buildings in Jersey City, and on Ellis and Bedloes Islands, at distances from 4000 feet to a little over a mile, and much glass broken in Jersey City and New York City, where the glass breakage extended as far north as 34th Street, or about $4\frac{3}{4}$ miles. The damage to New York was probably caused by the first explosion, as the barge was about 1000 feet nearer New York than the freight cars containing the T.N.T. The damage to Jersey City was caused by the second explosion.

As this disaster happened during the war, it was thought that the fire which was discovered by the night watchman had been started maliciously, but there was no proof that it was not accidental.

In connection with damage suits after the explosion at Black Tom, some interesting expert testimony was given:

"It is a fact of experience that there is generally wide disagreement between witnesses as to what they have actually witnessed concerning an explosion. When it has been shown by the effects produced that a series of explosions has resulted, there is generally a number of witnesses who will testify that there was but one explosion, and when there has been but one large explosion there are generally to be found witnesses who will testify that there were two or more explosions. There is generally much disagreement as to the relative force of a series of explosions, and the effects produced upon the witnesses, and disagreements as to whether the witnesses experienced a severer air shock or a severer earth shock, and which they felt first.

There is a great tendency to exaggeration in the popular mind as to the effects of an explosion and the danger to be apprehended from proximity to masses of high explosives. Consequently, when an explosion occurs, the suddenness and unexpectedness of the blast and the fear engendered shock the nervous system and tend to confound the senses of the witnesses.

The fact that there were 400,000 pounds of T.N.T. in the eight cars, four times as much as was carried on Barge 17, has led most persons to con-

clude that the seat of the first and more severe of the two explosions must have been in the eight cars instead of in the barge.

Now it can not be possible that the first and more severe of the two explosions could have occurred on land and in the eight cars of T.N.T., for the reason that a blast sufficient to produce a crater from 7 to 10 feet deep, 375 feet long and 175 feet wide, would certainly have killed some if not all of the railroad employees who were working in the vicinity of the switches drawing out trains.

A certain part of the T.N.T. in the eight cars burned up, but the balance exploded. Possibly a very considerable quantity burned up, but as the fire occurred on the end of the train farthest from the switches where the men were working, more of the material was consumed by fire at that end than at the other. Consequently, at the time of the first explosion the quantity in the cars next to where the men were standing was undiminished. The explosion of one carload of the T.N.T., that is to say, 50,000 pounds, would have been sufficient to kill them all in the positions where they were standing.

If a quantity of explosive has a certain intensity of action or effect upon a given object from a given distance, if the distance be doubled the intensity of the action is only a quarter as much, and if the intensity of the action is to be kept constant, the three dimensions of the explosive must be increased by two times when the distance is doubled, and this means that the volume of the explosive must be multiplied, not by four, but by eight.

The conditions which obtained in the explosion of the barge in close proximity to the water were such as to produce the maximum effect upon the water and upon the earth underneath—that is to say, to produce the maximum earth-shock for the quantity of explosive involved, and while a far greater proportion of the gases of the explosion of the T.N.T. in the barge must have been deflected upward into the atmosphere with consequent lessening of the direct lateral or horizontal atmospheric effect, still it was an unbarricaded magazine and consequently the magazines would have had to be at a distance of 3670 feet away from the barge, in order not to suffer severe structural damage; or about three times as far as was the actual distance of those buildings. The height of the six-story brick warehouses was such that the top of the buildings would easily come into the zone of the intense lateral blast from the barge, with the result that the roofs of the buildings would be blown off and the upper walls shattered, and the wall nearest the blast might likely have fallen outward toward the explosion, and later when the line of eight cars exploded, with the explosive more than four feet above the ground, there was great lateral atmospheric action in proportion to the quantity of explosive involved. The effect of the blast

from the exploding cars would be to complete the demolition of the walls of the brick warehouses.

There were 25,000 detonating fuzes on Barge 17. One of these detonators was found on shore three-quarters of a mile away from the barge, by one of the employees of the railroad company. Assuming that the barge was the seat of the first explosion, it is very conceivable at least that some one of the detonators may have fallen near one of the burning cars of T.N.T. with the melted T.N.T. flowing over the ground. in which case the detonating fuze falling into the burning T.N.T. would quickly heat and detonate, and in turn detonate the entire mass.

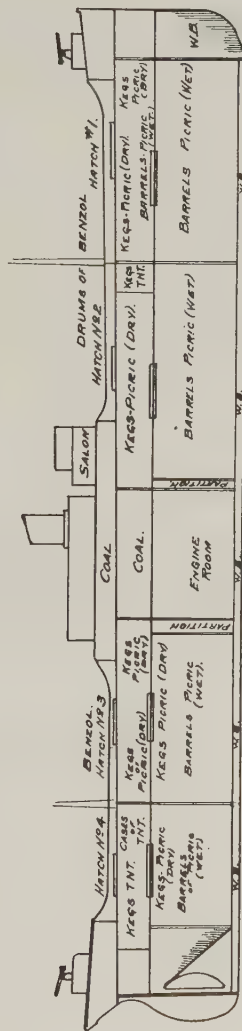
Barge 17 was more than 1,000 feet nearer to Manhattan Island than was the middle portion of the eight cars of T.N.T. A barricaded magazine containing 100,000 pounds of T.N.T. or other high explosives is required by the American Table of Distances to be placed at a distance of 1835 feet from inhabited dwellings, and when not barricaded, at twice that distance, or 3670 feet, it having been found that at such distances the intensity of action of that quantity of high explosive is not sufficient to cause serious structural damage. If the quantity of explosive were to be increased four-fold, the magazine would have to be moved farther away from the inhabited dwellings, but if barricaded it would only have to be moved 720 feet farther away, and if not barricaded, 1440 feet. If it were to be moved 1000 feet farther away, or as much farther away as were the eight cars of T.N.T. from Manhattan Island than was Barge 17, 500,000 pounds of T.N.T. could be stored in the magazine without increasing the intensity of action on a point 1,000 feet nearer to Manhattan Island than the barge in the event of an explosion."

SUMMARY

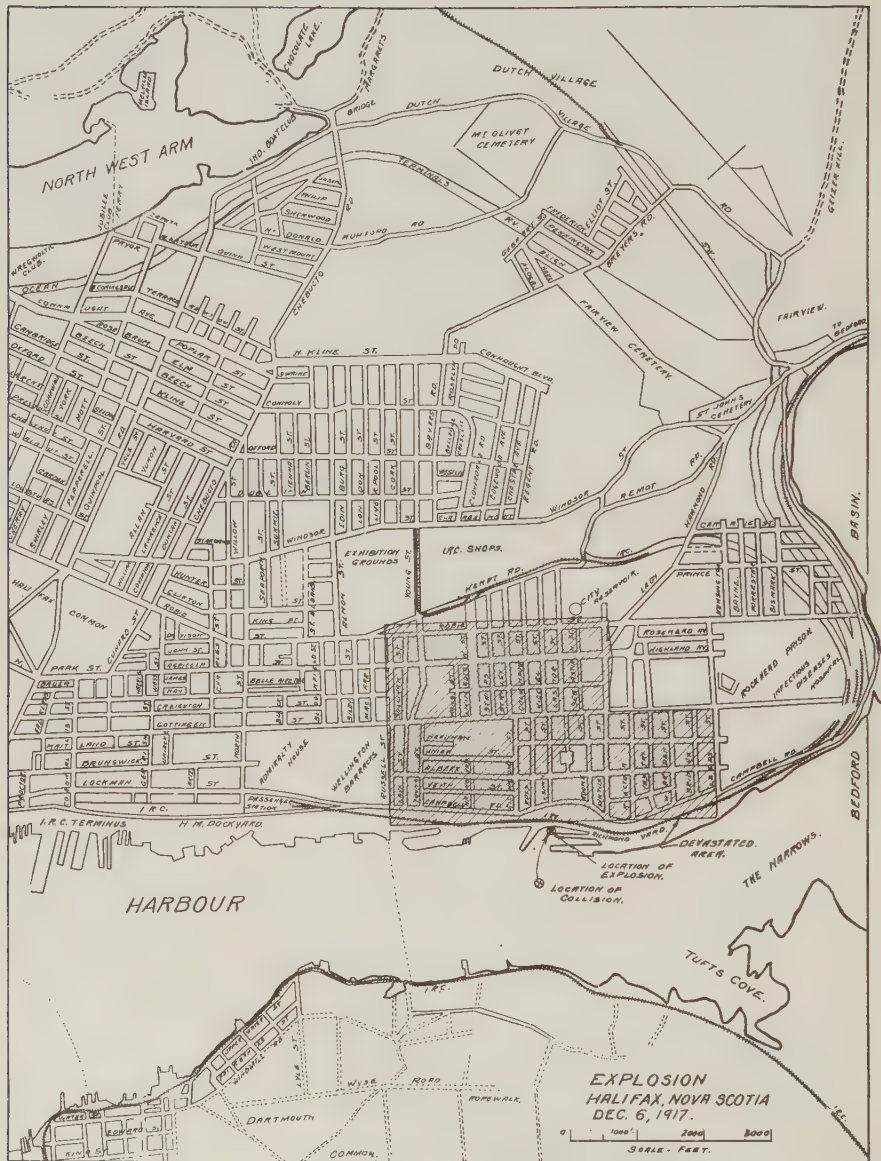
Building damaged	Protection	Extent of damage	Feet distant from explosion
Brick warehouses	None	Roofs off, walls shattered	1226 feet from barge
Hospital at Ellis Island	None	Doors and window frames pulled out Minor structural damage	1 mile from pier
Area of structural damage.....			
Glass broken, up to.....			4¾ miles
Missiles thrown, up to.....			1 mile

BULAWAYO, SOUTH AFRICA

On March 19th, 1906, at 3.50 P. M. an explosion occurred in a powder magazine at Bulawayo, South Africa.



CARGO
 S S. MONT BLANC.
 DEC. 6, 1917.



The magazine stood under the shadow of Range Kopjes, about three miles from town, one of seven magazines belonging to different dealers in explosives. The magazine in which the explosion occurred contained 100,000 pounds of dynamite.

Although 50 cases of dynamite were unloaded at the magazine earlier in the afternoon, the employee in charge had left and so far as reported, no one was killed or injured by the explosion. The cause of the accident was never known.

A crater was formed 50 feet deep and almost as wide on the site of the magazine. Although it stood almost in the center of the group of magazines, the contents of the others did not explode, but the buildings were all more or less damaged structurally. Dwelling houses of wood and iron buildings in the vicinity were wrecked. The damage in the town was extensive, but not severe, consisting principally of broken glass.

No figures could be obtained on which to estimate the limit of structural damage.

HALIFAX, NOVA SCOTIA

One of the greatest explosions of modern times, involving the largest amount of explosives, occurred on December 6th, 1917, at about 9 o'clock A. M., when the French ammunition ship "Mont Blanc" was rammed by the Belgian relief ship "Imo" in Halifax Habor, Nova Scotia.

The Mont Blanc, a small steamer, left New York on December 1st with a cargo of explosives for the French Government. In her hold was 450,000 pounds of T. N. T., 122,960 pounds of gun cotton, and 4,661,794 pounds of picric acid, wet and dry, making a total of 5,234,754 pounds. The wet picric acid was stowed in the lower hold of the vessel, fore and aft of the engine room. Over each hold of wet picric acid was stored the dry picric acid with the T.N.T. On the deck, which was iron with heavy bulwarks, there was loaded just before sailing 488,672 pounds of benzol in drums, the French Government having instructed their New York representatives just before the steamer left that such a commodity was very urgently required.

The Mont Blanc was directed to proceed to Halifax to join one of the convoys leaving that port to cross the Atlantic, and accordingly sailed there and anchored at the mouth of the harbor late in the evening of December 5th.

The Imo was to proceed from Halifax laden with food and supplies for the relief of Antwerp, and bore in large letters on her side the words "Belgian Relief." As the Germans permitted such ships an unmolested passage, she did not form part of a convoy, but was to pursue an independent passage.

The morning of December 6th was fine, with a slight haze and a few

degrees of frost. According to the report of Engineer Captain W. S. Frowd, R. N., on which this account is largely based, the two ships left their anchorage shortly after 8 A. M., the Mont Blanc inward bound to anchor in Bedford Basin and await the sailing of the convoy, and the Imo outward bound to cross the Atlantic.

The harbor at Halifax runs practically north and south, the northern part of the harbor opening into a large inland sheet of water known as Bedford Basin, while the southern part gives access to the Atlantic Ocean. Halifax is situated on the western side of the harbor, and the town of Dartmouth on the eastern side.

The Imo, on leaving the basin, instead of keeping to the Halifax side hugged the Dartmouth shore. Her master subsequently claimed that traffic prevented his taking the Halifax side as soon as he should have done, so permitting the ships to pass port to port. The result was that the ships approached each other bow on. Apparently the masters of the vessels simultaneously decided to alter course. The Imo headed off to her proper side of the harbor, and the Mont Blanc, dreading collision, decided at this moment to give way to the Imo. Both steamers gave signals, but for some reason never explained, they collided, and the Imo rammed the side of the Mont Blanc, striking about 12 to 14 feet abaft the bow on the starboard side. This occurred about 8.48 A. M.

Immediately the Mont Blanc burst into flame, due undoubtedly to the spilling of the benzol on the decks from the collision. It may have ignited from a spark generated by the two vessels on impact, or from the benzol reaching the ship's galley on the upper deck.

The master of the Mont Blanc realized the tremendous peril in which his crew was placed, and he and the crew of 18 men manned a boat, abandoned the ship, and pulled for the Dartmouth shore. They reached the woods before the explosion came, and only one man was killed. Afterwards the captain was severely criticized for abandoning his ship and not attempting to warn the surrounding vessels, but no steps that he could have taken would have minimized the results of the explosion.

The Mont Blanc, a mass of flames, drifted toward the Halifax shore, while the Imo backed away and was beached on the Dartmouth side.

Attention of people on shore was immediately attracted to the ship on fire and a call was sent in to the fire brigade. H. M. S. "Highflyer" which was lying near the burning vessel, promptly sent two pulling boats to try to pass a hawser to the doomed ship, so that she could be towed away from the piers she was approaching.

While these boats were so engaged, the burning benzol reached the explosives, and the disaster followed. At 9.05 A. M. came the explosion

on board the *Mont Blanc*, with a thundering crash, and a column of flame and smoke ascending hundreds of feet in the air.

The plates and other parts of the ship, raised to a white heat, were torn into fantastic shapes, forced upwards and outwards by the terrific pressure generated internally, and scattered over a large area of the city. Pedestrians were thrown against buildings and killed. Debris from the ship killed many people, and thousands were cut by flying glass. Onlookers watching the fire from various coigns of vantage were in many cases instantly killed. The crews of the boats of H. M. S. *Highflyer* were never seen again, and the *Highflyer* herself and the H. M. C. S. *Niobe* suffered many casualties among the crews on the upper decks.

Certain watchers in the Halifax citadel at 9.06 A. M. saw the mountain of black and white smoke shoot skyward, followed by an upheaval of water that drove enormous waves for two blocks up the sloping sides of the city. The force of the explosion created a sort of tidal wave that lashed the land and swept far out to sea. Ships were sunk at anchor and sailors killed on board. The bodies of 200 sailors, soldiers and riverside workers were afterwards recovered from the Narrows.

The harbor itself was in a bad state. Ships were drifting at the mercy of wind and tide, threatening disaster to those securely anchored or moored alongside wharves. Docks were wrecked, and thousands of tons of freight destroyed.

The people of Halifax had been constantly on guard against the possibility of bombardment by sea or by Zeppelins. Therefore when a rumbling was heard and clouds of dark smoke were seen, thousands ran to their windows and looked up into the air. Then came the force of the explosion which shattered the windows right in their faces, causing many severe injuries from broken glass, and blinding many people.

Among the principal buildings destroyed were five churches, three schools, a cotton factory, a sugar refinery, a foundry, an engineering firms' premises with graving dock, a railway terminus and two breweries, while great destruction was caused in the naval yard and naval hospital.

A fact naturally concealed as much as possible at the time was the damage which the naval yard suffered. It was the only repairing and storing base on the Atlantic shores of Canada for the ships of the British and Allied fleets, and consequently was of vast importance. Situated as it was in the devastated area, the damage inflicted on it was very considerable, and not a single building remained with a roof, while many were completely destroyed. Fortunately fire did not break out, as so frequently happened in other places, and the supplies for ship remained intact. The naval officers residing in the yard had to seek refuge in ships or with friends in the city after the explosion.

Many marvelous escapes from injury were reported. In one case, three men were working on the roof of a house. The tremendous air pressure from the explosion lifted them in the air to an unknown height; the pressure gradually subsided, and these men on top of an elastic medium came to the ground uninjured.

But it was on the adjacent shore that the calamity was most felt. Richmond, a suburb of Halifax to the north, received the full fury of the blast, and in an instant hundreds of houses were demolished completely, and hundreds of others permanently damaged, and the hapless inmates instantly killed.

The zone of the explosion extended for about three-quarters of a mile in every direction, and in this zone the destruction was almost complete.

Severe structural damage extended generally for a radius of $1\frac{1}{8}$ to $1\frac{1}{4}$ miles, although in the cases of the Arena Rink and the Chebucto School, both of which were badly damaged, the distances were figured from 1 to almost $1\frac{3}{4}$ miles from the point of explosion. Severe structural damage consisted of general racking of buildings necessitating extensive repairs, chimneys down, roofs partially off, doors, frames, windows and glass out, plaster down, beams cracked or displaced. Many fires were caused in this section by overturned stoves, and the same applied to the totally devastated area, although the evidence there was not so apparent because of the general destruction.

In the partially devastated area were such buildings as the railway depot, the roof of which collapsed, the King Edward Hotel, the city market, and other buildings which could be repaired. Numbers of individual cases of damage were reported at greater distances. For instance, a large three-story brick hardware store, $2\frac{1}{8}$ miles away had two or three rows of bricks under the roof overhang displaced and fallen in, and a small church at Herring Cove, at a distance of four miles from the explosion, had a concrete arch cracked.

It was estimated that 95% of all the glass in the city, both in the business and residential sections, was broken.

The town of Dartmouth, across the harbor, suffered the same damage in regard to wrecked buildings at distances from half a mile to a mile. Considerable damage was done at Bedford, nine miles away, and at Waverley, ten miles across the harbor, from glass breakage. It was reported that a few panes of glass were broken at Truro, 61 miles away.

The noise of the explosion was heard as far as the western shores of Newfoundland, 191 miles distant.

The after gun of the Mont Blanc was blown as far as Albro's Lake, a mile or two from the point of explosion, and the shank of the Mont Blanc's anchor was blown over the city and landed on the other side of the North

West Arm, a distance of three or four miles. Rivets, chains, links, pieces of deck gear and plate fragments were picked up a mile and a half from the water front.

The Halifax catastrophe had some characteristics peculiar to itself. While the property loss and homelessness resulting was widespread, it was not unparalleled when compared to disasters in other communities. But although the exact number of dead and wounded cannot be known, the loss of life was unprecedentedly great. As compared with 300 dead in the Chicago fire, and 498 lives lost in the San Francisco earthquake, the number of dead, identified and unidentified, in the Halifax disaster was reckoned to be 1,800 persons, and the registered number of wounded reached 8,000. What made this tragedy most sad was the great loss of sight, for it was estimated that at least 500 people were totally blinded or lost the sight of one eye. Another pathetic feature of the disaster was the destruction of schools in the city. Scholars were discovered killed or maimed at their desks, adding no small number to the casualty lists.

An unfortunate panic took place soon after the explosion when a military magazine caught fire. Although there was no danger, everyone left the afflicted area, and many who might have been saved were abandoned. The work of rescue was also halted on the evening of the very day of the explosion by a blinding snowstorm, a blizzard of almost unprecedented vigor driven by a fierce northwest wind, which added its share of suffering to the stricken city.

A big problem before the citizens that night was to provide accommodation for the thousands of homeless. Tents were erected in the common, and the naval and military authorities supplied blankets and other necessities as far as their means would permit, while householders who had accommodation freely opened their houses to the distressed, to the extreme limit of their capacity.

A single telegraph wire was left in Halifax that sent the news to the world to bring relief.

The very night of the 6th of December a train left Boston bringing doctors, nurses, medical supplies and appliances of which Halifax was so sorely in need, and their arrival was most opportune. Naturally this terrible event aroused sympathy all over the world, and unstinted financial aid was rendered.

SUMMARY			
Building damaged	Protection	Extent of damage	Feet distant from explosion
Buildings	See Note	Racked, Roofs damaged, beams cracked and displaced, 1¼ to 1½ miles	9240

SUMMARY—Continued

Area of structural damage.....	9240 feet
Missiles thrown.....	3-4 miles
Glass broken, in general up to.....	10 miles
Glass broken, in one instance.....	61 miles

The estimated distance required by the American Table of Distances for the total quantity would be approximately 12,000 feet if unbarricaded, or 6000 feet if barricaded.

NOTE:—Part of the explosives was below the water, and part above.

HASKELL, NEW JERSEY

At 9.22 P. M., on Friday, January 12th, 1917, a detonation in a smokeless powder glazing house at the south end of the Haskell Plant, near Haskell, New Jersey, started a series of fires and explosions which resulted in the destruction of 461,627 pounds of explosive, and completely destroyed twenty plant buildings.

The Haskell Works for the manufacture of nitro-cellulose and double base (nitroglycerin) smokeless powder was built along the small Wanaque River at the south end of Lake Inez, and backed with abrupt and high hills.

The origin of the disaster was a fire communicated to the glazing house on the A Line, in which nitroglycerin cannon powder (in the form of short single-perforated tubes) was being glazed with graphite in a sweetie barrel. This building contained two sweetie barrels, and the ordinary charge for each machine was 1200 pounds. The building and equipment were completely demolished by the explosion of the contents, and a crater was formed 8 feet deep under the building, indicating a very high order of detonation.

Fire was communicated to other buildings on the plant, and finally to a service magazine, well sheltered and protected by a natural rock barricade, containing 234,334 pounds of nitroglycerin cannon powder in bags. This powder exploded violently, and on account of the high perpendicular rock back of the magazine, the flame shot across the river, a distance of 700 feet, and involved three dry houses each containing about 26,000 pounds of the same explosives. It was the explosion in the service magazine which caused a very considerable amount of damage to the surrounding country. The explosion of 234,334 pounds of explosives in this magazine, and the 54,200 pounds in a rest house, a total of 288,534 pounds, was the quantity that did the damage.

The two operators in the glazing house were killed, and 13 people on the plant were slightly injured by flying missiles, or cut by glass. Outside the plant, 18 people were slightly injured, from nervous shock, or cut by glass, at varying distances and up to a mile in one instance.

The cause of the explosion was unknown. Fire was believed to have

started on a car standing in front of the shaker house, and then was communicated to the glazing house in which the first explosion occurred: As the disaster happened in war times, it was thought that the fire might have been started intentionally, but there was nothing to substantiate the suspicion.

The plant buildings containing powder in the order in which they were destroyed, together with the quantity of explosive in each house, were as follows:

Shaker house	2,400 pounds	burned
Glazing house	2,400 "	detonated
Dry house	26,000 "	burned
Rest house	8,700 "	detonated
Blending tower	83,013 "	burned and detonated
Rest house	54,200 "	detonated
Magaziné	234,334 "	detonated
Dry house	26,000 "	burned
Rest house	46,580 "	burned and detonated
Cars	4,000 "	burned
<hr/>		
Total	461,627 "	

Eleven other plant buildings in the vicinity of the explosions but containing no powder, were totally destroyed, including the blending and packing house, store houses and motor houses, and change house for employees, all of which were either burned or destroyed by the explosions.

On the west side of the lake the following plant buildings suffered minor structural damage:

- Solvent sections (15).
- Experimental solvent house, and barricade.
- Change house.
- Spare parts building.
- Refrigerating plant.
- Carpenter shop.
- Water dry house and barricade.

To the north, a water dry house at a distance of about 1000 feet from the center line of the explosion, was the limit of structural damage. Window breakage to the north was universal up to about 1500 feet.

On the east side of the lake, across from the site of the explosion, structural damage extended farther, to a dry house about 1500 feet from the central point of the explosion.

At Blasting Cap Works, across the river and protected by a hill from the full force of the explosion, the structural damage was as follows.

Building	Distance from explosion [Feet]	Nature of damage
Carpenter shop	2000	Splice bolts on bottom chord of center truss sheared off. Truss sprung apart.
Loaded detonator store	2000	North end of building smashed in. 40—2x4 studding on west side sprung in.
Store room	2000	20 truss cracked and split. Trusses made of 2x6 rafters and collars. West side of building bulged out. 2x4 studding and siding ripped out.
Main office	2000	15—2x8 rafters on north and west of building split and shattered.
Assemble building	2000	20 rafters 2x8 on west side of building split.
Brine condensor	2000	Brine pipe broken.
Fulminate factory	1600	West side bulged.
Storehouse	1800	West side bulged out about $\frac{3}{4}$ of the length. East side bulged out about $\frac{1}{2}$ length. Sills broken off foundations. Bottom chord of one roof truss 6x6 broken.
Shell plant, new part	1800	Four roof truss broken. Structural iron lifted about 6 inches, breaking loose top courses of brick on outside walls.
Nitric Acid store	1800	Sills partly off foundation. Roof trusses bottom chord broken.
Barn	1800	Building badly racked. Studding on west side shoved out of place.
Storehouse	1800	North end bulged out.

On all these buildings there was also a large amount of minor damage, consisting of sash blown out, doors blown off hinges, glass out, etc.

At an E. B. Cap Works, to the south of the explosion and unprotected, the structural damage was as follows:

Building	Distance from explosion [Feet]	Nature of damage
Machine shop	2700	40 rafters on north side of building split. Glass broken, other minor damages.
Cap store	2600	10—2x4 studding on north side of building broken, and siding bulged in.
Men's change house	2700	North end of building bulged out, 6—2x4 studdings broken.
Change house	2700	Two concrete piers, one under extreme north end center of building the other about 20 feet south of the first pier on the center of building, sprung out of plumb.
Carpenter shop	2700	3—2x12 rafters on north side of building split from eaves to ridge.

There was also a large amount of minor damage to the above buildings, consisting of doors blown off hinges, glass and sash blown out, etc.

On account of the conformation of the ground, the main force of the explosion went south down the river towards the E. B. Cap Works and the towns of Pompton Lakes, Pompton Plains, Bloomingdale, Oakland, etc.

After considering 1300 claims for property damage, the following list was tabulated to indicate the limits of serious structural damage outside of the works area:

Building	Distance from explosion [Feet]	Nature of Damage
Residence	4400	Three 2x8 floor beams in attic buckled down about 3 inches, badly cracked at point of buckle. Considerable minor damage.
Silk mill	2500	Boiler house wall cracked from top to bottom of foundation. Nine inch brick wall. (Wall may have been cracked previously), Purlin 2x12 broken in mill building. In the boiler house 3—2x10 roof rafters broken. Shed at storehouse had side blown out. The minor damage in connection with this property was very great, on account of the type of construction of the building.
Store	4100	Constructed of concrete blocks and reinforced concrete. Cracks in the walls of this building extended from under the second floor windows down to and through the foundations. In some cases these cracks had existed already, but were widened by the force of the explosion. Considerable minor damage also.
Post Office and Bank	4150	Concrete blocks and reinforced concrete Three 2x4 floor beams raised 2 inches in the post office building. Beams split at point of raise about 2 feet following grain of wood. Concrete walls cracked on all four sides, cracks extended from under second story windows down to and through the foundation. Considerable minor damage also.
Residence	4250	Brick walls of this house slightly cracked. Interior partition sprung out of line about an inch. South outside wall slightly sprung outward. Considerable minor damage.
Store and residence	4250	Stucco on cement blocks showed cracks on north and south sides from eaves to bottom of foundation, as well as minor damage.
Store and apartments	4250	Concrete block building showed cracks from roof to bottom of foundation. Considerable minor damage.
Hotel	4600	Quite an old building. One interior partition shifted about one inch.

Building	Distance from explosion [Feet]	Nature of damage
Store and apartments	4800	The rear end of this house, or apartment above second floor, moved out about one inch. Considerable plaster cracked, glass broken, doors off, and other minor damage.
Residence	6400	This building was about 125 years old. Built of stone masonry 2½ feet thick, covered with stucco. Portion of wall over window in dining room cracked, brick pier in cellar badly cracked. Walls near fireplace in living room cracked, dining room the same. Chimney at rear of house cracked from top to bottom. Arch over stairway cracked.
Residence	4600	Partition 2x4 studding covered with lath and plaster moved at the bottom about ½ inch. Considerable other minor damage.
Residence	4600	North wall of house slightly bulged in, not cracked. Considerable other minor damage.
Residence	5600	Interior partition, 2x4 studding covered with lath and plaster, moved slightly at base.
Residence	4600	Considerable minor damage, plaster down, glass blown out, etc.
Residence	4600	Considerable minor damage.
Residence	4600	Considerable minor damage.
Residence	4500	Concrete floor in basement sagged and cracked. Foundation of chimney loosened and cracked. Girder through center of building sagged and cracked. One 2x6 roof rafter cracked. Two chimneys cracked. Large amount of minor damage, window and door frames blown out, plaster down. A very old property, in first class order. Walls of stone masonry about 2 feet thick.
Residence	3000	Minor structural damage.
Residence	2900	A one-story frame structure partly sheathed. One 2x6 rafter split from eaves to point 6 feet from eaves on north side of house. Four 2x6 rafters split through entire length. Minor damage to doors, windows, etc.
Residence	2500	A frame structure. Four roof rafters, 2x6 broken and the roof sagged in. Considerable other minor damage.
Theatre	3600	Concrete block moving picture theatre. Cracks from eaves to bottom of foundation on the south side of the building. Residence and store adjoining slightly moved on foundation.
Residence	5500	Two cracks in large brick fireplace. Other minor structural damage.
Residence	3600	Frame building. Roof lifted and dropped back ½ inch out. Stair loosened from wall.

Building	Distance from explosion [Feet]	Nature of damage
Residence	5600	Chimney cracked and pulled away from house. Considerable minor damage.
Motor Inn	6300	Arch over dining room door cracked, allowing one inch settlement. Arch was made of plaster. Considerable minor damage.
Garage	6400	Poorly constructed building, made of one thickness of concrete block. Light galvanized iron roof, with very light framing. Walls cracked from windows to foundation, also in several places cracks from eaves to foundation, probably due to settlement of building. All windows and doors blown out.
Residence	6500	Old frame residence, in good repair. Fresco and plaster arches broken throughout the house, generally in several places.
Garage	6800	Concrete block garage, cracked from eaves to foundation on the north side. This property was in a direct line with the explosion. Cracks originally existed due to settling of the building, but were widened by the explosion.
Residence	6500	Plaster arch in upper hall cracked and settled one inch.
Printer's Shop	6200	Building in bad condition, foundation decayed, shop settled on one side. Upper floor overloaded with surplus type. Building settled still more from force of the explosion.
Residence	6300	Front wall drawn out about $\frac{1}{2}$ inch. Building constructed of solid reinforced concrete with wooden floor beams and floor, also wood framing of roof. Porch had concrete floor and wooden frame columns and roof. Porch floor bulged up 2 inches, wood frame of roof torn loose. Much minor damage.

Careful consideration of the damage to structures in the vicinity of the explosion limited the area of substantial structural damage to approximately 4500 feet.

Missiles were thrown 2250 feet. Glass was broken in Pompton Lakes, at a distance of a mile and a half, and this was the limit of any general glass breakage.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Buildings	No	Floor beams broken, etc., up to	4400
Area of structural damage.....			4400 feet
Charted.....			2200 feet
Glass broken, up to.....			1 $\frac{1}{2}$ miles
Missiles thrown, up to.....			2250 feet

KIMBERLEY, SOUTH AFRICA

At 3.20 P. M., on January 10th, 1884, occurred a serious explosion of about 30 tons of dynamite in a group of 16 magazines at Kimberley, South Africa.

These magazines were distributed in a long straggling group in the south-east corner of De Beer's mining area, and were spaced from 50 to 100 feet apart. They were huts, built of light wooden framing, covered with thin corrugated iron. Some had a 9 inch lining of sundried bricks. Nos. 1, 2, and 16 were empty, and the others held 96,870 pounds of dynamite, 7,500 pounds of potentite, and 30,346 pounds of gunpowder; also 1,053 boxes of detonators, 340,350 sporting cartridges, and 75 cases of paraffin. In five out of the thirteen huts in use, detonators and dynamite were stored together.

There were two explosions, separated by a few seconds of time, and prior to the first, fire and smoke were seen at the north end of the site.

The paraffin was stored in a hut by itself, between two dynamite magazines. Two Kaffirs, were waiting to unload a wagon of dynamite, and it was thought that they might have caused a fire in the paraffin hut by carelessness with matches as they smoked and waited. They were the only men seen in the vicinity of the magazines by the white overseers. Their bodies were found about 300 feet from the site, about 120 feet apart, in such a position that it was reasonable to infer that they were trying to escape. Another native was killed at the same distance, and still another, working 600 feet from the explosion, was so seriously injured by projected debris that he died the following day. One other person was injured in addition to the four who were killed.

In the opinion of the inspector at Kimberley, the two tons of gunpowder in No. 7 hut were the first to explode, and the second and main explosion was caused by a large charge of dynamite in one of the huts exploding, and causing the simultaneous explosion of dynamite in other huts by sympathetic detonation.

The 31,450 pounds of dynamite in No. 5 hut made the largest crater, 40 feet by 5½ feet deep, and 15,950 pounds in No. 6 also made a large crater, 35 feet by 3 feet deep. The potentite burnt away without exploding.

There was no dynamite in Nos. 8 and 9 huts. In No. 10 only one case 50 pounds, was burnt, and the other cases, containing 3,500 pounds of dynamite, did not explode. This was a brick-lined hut. In No. 11, 750 pounds of dynamite exploded, forming a hole 3 feet deep. There was no explosion in Nos. 12, 13, 14 and 15. No. 13 hut contained 18,400 pounds of dynamite.

The main explosion, therefore, consisted of the dynamite in Nos. 5, 6, and 7 huts; 31,450 pounds, 15,950 pounds and 19,450 pounds respectively, or 66,850 pounds in all, or 30 tons.

The destruction was very complète, 12 magazines entirely destroyed, and the other 4 partly standing, but in ruins.

The nearest building to the magazines was the wood yard of the Victoria Diamond Mining Company, which was completely destroyed. Doors and shutters were burst open within a radius of a mile and a quarter, ornaments shaken from shelves at distances up to two and a half miles.

The town of Kimberley, about three-quarters of a mile away, was screened by debris heaps and by the character of the ground, and escaped structural injury. Men at a distance of 1500 feet, unscreened from the explosion were unhurt.

The danger range from projected debris was greater than for structural damage from concussion, which only reached to a distance of about one mile.

This explosion was not valuable as a measure of structural damage, but was interesting in regard to the quantity of explosive involved, and the circumstances of the explosion.

KOBE, JAPAN

At 6.40 A. M. on April 7th, 1910, there was an explosion on board a lighter in the harbor of Kobe, Japan.

Three foreign firms, representing the interests of Nobel's Explosives Company, had been allowed by the Japanese Government to store their high explosives in the magazines and "go-downs" at Osaka Arsenal. A small explosion in Osaka aroused popular fear, and caused the government to rule that no magazine should contain more than 7000 pounds of explosive, and that everything in excess of this amount should be removed. Much of Nobel's explosive was therefore taken from Osaka in July, 1909, and placed aboard lighters moored just beyond the limits of Kobe Harbor. New shipments of powder from Germany and England were stored in the same way. This was in accordance with the law, and the lighters were regularly inspected by the authorities.

On April 7th, the four lighters containing explosives were moored 4000 feet from shore, 300 feet apart. Three of them were without special decks or arrangements for the transportation of powder, but the one nearest shore, in which the explosion occurred, was the hulk of one of the old Baring vessels of the closed type, built entirely of wood with copper fastenings, and rebuilt for the explosive trade. It had been examined and passed by the authorities. It contained 1000 cases of new gelignite, 1700 cases of old gelignite, 3000 cases of new dynamite, 331 cases of old dynamite, or 6,031 cases in all, totalling 301,550 pounds, as well as 110 cases of detonators.

All the barges were heavily loaded, so that only a small portion of the cargoes, about one-fourth, was above the water line.

Watchmen were stationed on the lighters permanently, day and night. Their food was carried out to them from shore, so that there would be no danger of fire from cooking on board. The lighter nearest shore had a small house erected near the stern, away from the hatches, and the Japanese night watchman, who had been drinking, built a little fire there to dry his clothes early on the morning of the explosion. At 6.30 A. M. smoke was seen pouring out from the under side of the canvas cover of the forward hatch, and the three watchmen on the other lighters, on seeing the smoke, took warning and jumped overboard. They were picked up by sampans. The explosion followed in ten minutes, totally destroying the lighter and killing the watchman.

The contents of the other three lighters did not explode, but the boats were injured to such an extent that they gradually filled. The following day, a strong wind raised a heavy sea, causing them to become water-logged, and to lose some of their contents. Much of the cargo was salvaged some days later. Only slight damage was done to shipping, and the nearest vessel to the point of explosion, the *Inveric*, moored about a mile away, was uninjured.

The topography of the land front of Kobe Harbor is interesting as having had some possible influence on the damage in the city. The ground rises gradually almost from the harbor front for about a mile, where it reaches the foot of the hills. Beyond that, the rise is very abrupt, almost precipitous, forming a wall-like barrier, at an average distance of about a mile and a half from the harbor line.

Much damage was reported at Kobe and in villages along the coast at distances up to 8000 feet. In Kobe, a thickly populated city, thousands of houses were injured, entailing much loss, especially to poorer people living along the water front. No one was killed with the exception of the watchman whose fire was considered the probable cause of the explosion; but over 100 people were injured, many of whom were cut by flying glass at distances as great as 7000 feet. Glass was broken eight miles away. A five foot anchor from the lighter was picked up near the railway a mile and a half from the explosion.

In estimating structural damage the type of Japanese house should be considered. The damage reported in Kobe and the outlying villages at distances up to 8000 feet from the explosion, occurred in native houses. The Japanese house is not built of bamboo and paper, as popularly stated, but as a rule has a rather strong and flexible frame of timbers, forming a skeleton, filled in with an open network of bamboo strips, and sheathed with coarse mud plaster, forming two walls to the house. The partitions, which slide in shallow grooves, are called "shoji". They are light latticed frames covered with paper, and have no power of resistance. Consequently, all

damage reported concerning Japanese houses offers no guide as to the power of the air pressure. The "serious damage" reported in houses of this character means broken shoji, glass, and family utensils belonging to poor Japanese who could ill afford even small losses.

The few foreign built houses were of flimsy construction. Nothing but superficial damage was done, and none of these foreign buildings were capable of resisting even a slight air pressure.

At the Oriental Hotel on the Bund, a building much more substantial in appearance than in fact, the windows and door frames on the side facing the explosion were blown in. These frames were not set into the adjoining walls, but were merely in contact with them. The air wave also lifted the glass dome, thirty feet in diameter, supported by a steel framework, and shattered the glass, but did not injure the framework. The hotel was about 4000 feet distant from the explosion.

At the Gas Works, 5000 feet away, the explosion made a rent in the gas tank, causing the gas to escape, and collapsing the tank. Cracks also appeared around the fire boxes of an old brick furnace, but this brickwork was old and weak.

At the Boat House, 6000 feet distant, doors were blown in.

At the Old Gymnasium, 6000 feet away, two large pieces of ceiling fell.

At the Missionary Institute and Chapel, 7200 feet away, plaster was bulged, windows and frames broken, and doors wrenched open.

Beyond 7000 feet, damage was superficial, consisting principally of glass breakage.

The explosion at Kobe teaches nothing of value in regard to structural damage from explosions. Nowhere was there any damage which might be considered as seriously weakening or breaking some integral part of a building, such as foundations, main supports of walls, floor and roof supports in buildings as substantially constructed as the average American house.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Buildings of light construction	Water	Slight damage, windows and doors, plaster and glass. No structural damage	7000
Missiles thrown, in one instance			1½ miles
Glass broken			8 miles

LAKE DENMARK, NEW JERSEY

On July 10, 1926, there occurred a series of explosions on the Lake Denmark Ammunition Depot of the United States Navy (about 3½ miles

from Dover, N. J.). This depot comprised an area of 461 acres of land, partly overgrown by trees and brush. It included approximately 160 buildings, 44 of which were used for the storage of high explosives, smokeless powder, projectiles, black powder, the remainder being store houses, industrial buildings which did not contain explosives, and dwellings.

On the afternoon of July 10, 1926, there was a severe electrical storm at Lake Denmark. At about 5.15 P. M. lightning struck in the southwest end of the depot, and almost immediately thereafter, black smoke was seen issuing from the northeast side of Temporary Magazine No. 8. An alarm of fire was sounded and the personnel of the depot responded immediately to the fire call, and at least one stream of water was playing on the fire when at 5.20 P. M. a tremendous detonation occurred at the scene of the fire.

The first explosion occurred in Temporary Magazine No. 8, and was followed in about 5 minutes by the explosion of the contents of Temporary Store House No. 9, which was about 150 ft. in the clear from No. 8. Enormous craters were made by the two explosions.

The buildings used for the storage of explosives were of fireproof construction and equipped with lightning rods of an ordinary type.

The first explosion did considerable damage to other magazines and buildings of the depot, exposing the contents of the buildings to flaming debris from the second explosion. Buildings in the immediate vicinity of Temporary Store Houses Nos. 8 and 9 were ignited by embers, missiles or direct heat from the explosions, and the fire spread rapidly to the other magazines, storehouses, and shell houses.

Temporary Store Houses Nos. 8 and 9 were one-story hollow tile, or brick and hollow tile buildings, with wooden roof boards and roof sheeting supported by steel trusses and steel purlins.

Temporary Store House No. 8 contained:

2106—50 lb. cast T.N.T. depth charges—north end. Detonators removed.

850—aerial bombs T.N.T. center section.

1800—300 lb. depth charges T.N.T. middle door to south end. Large amount wooden dunnage—wooden boxes.

100—25 lb. Navy Mark I, loaded and plugged (air craft); accessories for bombs—fins, tails, etc., in wooden boxes.

The temperature in this building on Saturday ran from 22 to 27 deg. C. Estimated total amount of explosives in this building 670,000 lbs.

Temporary Store House No. 9 contained:

1,250,000 lbs. Grade "A" flake T.N.T. in 50 lb. boxes—stored from middle door to south end of building.

350,000 lbs. Grade "A" T.N.T. stored in 100 lb. boxes north end.

Between north and south piles 150 to 160 Mark IV air craft bombs. Total weight about 500 lbs. Probably 250 lbs. T.N.T. each bomb.

Estimated total amount of explosive in building over 1,600,000 lbs. T.N.T.

A third serious explosion occurred in Shell Store House No. 22. The contents of Shell Store House No. 22 were:

40—14" Class "B"—loaded and fused.

80—14" A. P.—loaded and fused.

360—Mark I bombs—loaded 50 lbs. T.N.T.—boxed.

1,000—Mark II—loaded 50 lbs. T.N.T.—boxed.

300 to 400—Mark III—loaded T.N.T.

200—Mark IV—loaded T.N.T.

500—Mark V—loaded T.N.T.

10,000—8" shell—loaded and fused.

1,000—5" shell—loaded and fused.

There were three distinct sub-craters in the big crater where this building was located; two of which were deep and well defined, and the third shallow but distinct.

Estimated total amount of explosives in building 180,000 lbs.

There were also a number of minor explosions.

Within 3000 ft. radius of Temporary Store Houses Nos. 8 and 9 everything on Lake Denmark Depot was wrecked, burned or otherwise destroyed, with a few exceptions that will be noted.

Beyond the 3000 ft. radius, and as far as the Navy reservation (estimated under 5600 ft.), all of the buildings were damaged in more or less degree by the explosion, but as there were no explosives or powder stored in the buildings in this area, no fires occurred. The exceptions to this general statement were a number (about 10) of sub-surface magazines varying in distance from 2200 to 4000 ft. These buildings were concrete structures about 18' x 12' buried in the hillside with a stone face retaining wall in front parallel with the road. The concrete roofs of these magazines were covered with earth probably to a thickness of two to three feet, and the sides were protected by earth embankments. Practically all of these magazines contained black powder. None of them were damaged and the contents remained intact, except sub-surface magazine located about 1200 ft. away, between Magazine No. 2 and Temporary Store No. 23, and the only damage to this particular magazine was that a few stones fell out of the front retaining wall.

In the south area, the typical and general construction of the store houses was concrete foundations, tile walls or tile and brick walls of various thicknesses, steel roof trusses either supported direct on the walls or on light

steel columns in the walls; steel purlins, 1" roof sheathing covered with asbestos shingles, asbestos paper or tar roofing. In many instances all that was left of the buildings were bent and twisted structural steel members and remains of the crushed and demolished walls. Except in the buildings where explosions occurred concrete foundations and floors were almost undamaged.

There were a few buildings of steel frame construction covered with corrugated iron. The corrugated iron siding and roofing were ripped off by the explosions which probably also damaged the steel frame to some extent, which was further twisted and bent by smokeless powder fires in adjoining buildings.

The power house, distant 1850 ft., was a substantial brick building with steel roof trusses and a 4" cinder concrete roof slab covered with slate. The adjoining Administration Building, distant 1700 ft., was also a brick building. Storehouse No. 3, distant 800 ft., was a two story reinforced concrete frame building with steel roof trusses and tile curtain walls.

Shell House No. 7, distant 3200 ft., at the extreme north end of the south area was a two-story reinforced concrete frame building with concrete floors and heavy brick walls. The Carpenter Shop distant 2200 ft., was a one-story brick building. The marine barracks, distant 3200 ft., was a wooden frame building stuccoed and of large area. The two employees houses near the marine barracks, distant 2850 and 3350 ft., occupied as officers' quarters, were brick buildings. The dispensary, distant 3100 ft., was a low one-story building of frame set on concrete foundations. Temporary Building No. 7, distant 3300 ft., was a brick building with steel roof trusses. The adjoining magazine No. 5, distant 3550 ft., was a brick building with steel roof trusses.

In the south area there were a number of other miscellaneous structures of varying construction. A number of employees houses were located in the extreme south section forming a semi-circle around temporary buildings Nos. 8 and 9 in which the explosions occurred. All were demolished and furniture, clothing and other contents were a mass of debris.

Observations indicated that buildings with structural steel roofs are certainly a large missile hazard. Sections of roof beams and pieces of angles and other structural steel badly twisted and bent were noticed everywhere on the depot grounds. Most of the sections that were noticed were from four to seven feet long and would have penetrated any light roof construction. The same thing, of course, applies to the numerous projectiles that were thrown in large quantities all over the depot.

Probably one of the outstanding matters of interest was that the following explosives stored did not detonate, but burned:

2,500,000 lbs. Explosives "D" stored in temporary No. 11 about 500 ft. away from site of explosion.

300,000 lbs. of Explosives "D" and 20,000 lbs. of Picrate Acid in Dry House No. 1, 750 ft. away from the site of explosion.

300,000 lbs. of Explosives "D" in Dry House No. 2-300 ft. from the site of explosion and only 50 ft. from Dry House No. 1.

510,000 lbs. of T.N.T. in bulk burned in temporary building No. 7 near the marine barracks.

Some of the brick walls in the buildings in which explosives were stored and burned were glazed showing that the heat was so intense that it melted the bricks.

The smokeless storehouses, most of them of very substantial construction, were so shattered by the first explosion and then damaged by the outburst of fire that they are almost completely wrecked. Brick walls seem to have withstood the explosions and fire much better than even substantial tile walls. The tile walls were almost invariably completely pulled down by the collapse of the trusses, while in many instances brick walls are standing up with the steel trusses collapsed in between the walls.

The power house was somewhat protected by the topography from the site of explosions but the concrete slab roof was crushed in and the fact that this roof slab crushed instead of offering resistance probably accounts for the fact that the high brick walls were still standing, although so cracked in places that they would probably have to be torn down. A brick stack in the rear of the power house was almost intact except a crack about 15 or 20 ft. deep from the top of the stack.

The fire spread out from the south end of depot gradually diminished as it reached 2000 to 2500 ft. This was also noticed at the east end in the row of shell houses, particularly S. H. No. 16, distant 2800 ft., to S. H. No. 11 distant 3200 ft. S. H. No. 16 was practically completely gutted, while S. H. No. 11 was still partly standing with the intervening buildings in various stages of destruction.

The marine barracks, distant 3175 ft., were undoubtedly somewhat wrecked by the explosion and finally caught fire and burned to the ground. This building actually collapsed on fire about 11 o'clock Sunday morning about seventeen hours after the first explosion, which would give some idea about the length of time that the fire required to reach this point. Employees houses, distant 2800 ft. and 3275 ft., in the vicinity of the marine barracks were brick buildings, the walls of which were partly wrecked, as were also the roofs. The small frame dispensary, distant 3025 ft., near the marine barracks escaped serious injury, although the interior plaster board of course fell down.

In the north area the residence, distant 4350 ft., of the officer in charge was a substantial stone building which was not seriously damaged except by falling plaster, breaking windows and doors. The same thing applies to the brick stable nearby, distant 4250 ft.

The storehouses (about 30) in the north area (beyond 4000 ft. and up to 5600 ft.) were almost entirely what is known as Austin buildings with concrete foundations, 8" tile walls with pilasters under the trusses and in some instances light steel columns on the pilasters; steel trusses or steel girders with steel rafters sheathed with roof boards and paper roofing. These buildings were in various stages of demolition and indicate clearly the lack of structural strength of tile under shock. The roofs were not so badly damaged but the tile end and side walls were crushed in with, in many instances, part of the side walls hanging to the still standing roof.

Adjoining the Lake Denmark Depot was the Picatinny Arsenal of the U. S. Army. The Picatinny Arsenal lay about 150 ft. below the point on the hillside on which was the site of the Temporary Magazines Nos. 8 and 9.

Approximately the slope of the ground on Lake Denmark Depot continued through the Picatinny Arsenal down to Picatinny Lake. Bordering the Lake the ground was practically level, to the west the ground rises gradually, then rises abruptly to a higher elevation than the hills east of Lake Denmark Depot.

The level land of Picatinny Arsenal was fairly well cleared, except the east end, and the west hillsides which were wooded.

Practically all of the buildings on Picatinny Arsenal were placed at a lower elevation than the buildings in which the explosions occurred, and as there were no barricades, etc., were directly exposed to the force of the explosions, except for such protection as was afforded by the trees surrounding the location.

The area occupied by Picatinny Arsenal was approximately three miles long by three-quarters of a mile wide, and scattered over were the 350 or so buildings of a miscellaneous character, which comprised the Arsenal.

When the explosions occurred in Temporary Storehouses Nos. 8 and 9, a wave of tremendous pressure was thrown over the Picatinny Area, intensified probably by the hill back of buildings 8 and 9. The wave broadened out as it proceeded until it finally struck the hills to the west, but just how it finally struck the hills to the west, and how it reacted from then on is difficult to establish, but coming or going it spread over the entire valley causing destruction or damage.

The buildings on Picatinny Arsenal were of many different kinds of construction and size, and in some instances more or less protected or screened by standing woods or by other buildings. This report in addition to describing the damage done also makes comparisons of differently con-

structed buildings of about similar exposure as well as to point out from a construction standpoint any special features. The report is based on what was actually observed and no attempts made to actually figure the theoretical strength of individual structures or structural members.

1000 FT. TO 2000 FT. ZONE:

The first buildings in this zone were:

- Bldg. No. 281—Guard Headquarters—frame, distant 1050 ft.
- “ “ 282—Garage—frame and corrugated iron, distance 1200 ft.
- “ “ 280—Searching Shed—frame, distance 1100 ft.
- “ “ 75—Cotton Picker & Dry House—frame and corrugated iron, distance 1200 ft.
- “ “ 76—Cotton Dry House—brick, distance 1200 ft.
- “ “ 126—Stables and Sheds—frame, distance 1100 ft.
- “ “ 239—N. C. Nitrating House—Four story hollow tile, distance 1150 ft.
- “ “ 240—N. C. Nitrating Fan & Pump House—frame, distance 1150 ft.

The above were completely demolished.

Building No. 38—General Storehouse, distant 1250 ft., was a brick building almost entirely wrecked and on fire. After explosion and fire the end walls, including the gable ends, were still standing.

Building No. 369—Frame Shed over Tanks, distant 1100 ft. Building completely demolished but the tanks inside as well as several tanks outside remained on their foundations.

Building No. 77—Two-story Boiling Tub House, distant 1250 ft. Tile walls, wooden roof trusses and wooden floor beams. Building completely wrecked.

Building No. 74—Main Power House, distant 1500 ft. Substantial brick building of considerable height with interior steel columns and steel supported floors, steel roof trusses, concrete roof slab, slag roofing. Roof almost flat. While the north and south ends of the building are badly demolished, the center portion, including two stacks, were still standing as was also the coal conveying system on the south end and the ash skip hoist at the north end, all of which was evidence of the strength of steel construction and brick buildings well braced on the inside and with comparatively flat roofs.

Building No. 118—Main Office, distant 1500 ft. Two story and attic main building with an ell extension towards the south, the latter used for record store. The complete wreck of the rear addition and the end of the building away from the explosion and the brick end wall and part of the

other which were still standing intact, gave further evidence of the strength of a substantial and well built brick wall.

Building No. 54—Millwright Shop, distant 1750 ft. One-story brick building, 21" brick walls with pilasters, steel roof trusses covered with 3" plank, slag roofing.

Roof completely crushed in and end of building away from explosion blown out which probably was caused by the direction in which the pressure was applied on the roof. Roof trusses twisted and distorted caused by the extreme pressure applied to the entire roof surface. Brick walls except end wall away from the explosion standing practically intact. Machinery in the building did not appear to be badly damaged.

Building No. 108—Laboratory, distant 2050 ft. One-story and basement brick building. This building was located just outside the 2,000 ft. zone. Roof and interior of building completely demolished but the brick walls were standing practically intact, showing that the damage to this building was done by the roof crushing in.

Northwest of the Main Office, distant about 1800 to 2200 ft., there were a number of buildings, mostly small and of frame construction, which were completely wrecked. In one of these buildings, distant 2100 ft., was stored at the time of the explosion, 40 lbs. of dry guncotton which exploded, scattering the frame building over a limited area. A nearby building contained about 50 lbs. of 30% moisture guncotton. This guncotton as well as the building burned.

In this vicinity there was also located a Paste Storehouse which contained at the time of the explosion about 100 lbs. of N. G. in alcohol solution and about 15 lbs. of N. G. paste. The frame building was demolished but the contents were not damaged.

Building No. 325—Raw Materials Storage, distant 1800 ft.—for H. E. Plant. This was a three-story building with steel frame set on concrete foundations forming the first story side walls of the building. Steel columns encased in concrete. Steel floor beams with concrete floor. Reinforced concrete roof slab practically flat slag roofing, tile curtain walls.

The only real damage to this building was the collapsing of portions of the tile curtain walls. Frame, floors and roof practically intact.

This building although more exposed was in better condition than adjoining buildings which were of similar construction but not quite so well braced on the inside, showing the advantage in comparatively high buildings of well braced and tied together steel frame.

Building No. 55—Brick Storehouse, distant 1850 ft. One-story building 18" brick walls, steel roof trusses, slate roof.

Roof trusses collapsed under pressure on the side towards the explosion completely pulling down the entire roof structure, but the brick walls were

only partly down. The roof trusses in this case appeared to be of about ordinary construction and designed to withstand ordinary wind pressure, snow loads, etc., with about one-quarter pitch, but evidently the trusses were not strong enough to withstand the tremendous pressure exerted on the roof surface and transmitted by the purlins to the trusses. This particular feature will be frequently referred to in the following and it is sufficient that the increased snow load and similar load by using a flat type roof is of no comparison whatsoever with the pressure of the explosive wave such as here occurred, and that a flat type roof is of great advantage in the vicinity of possible explosions.

Building No. 56—Brick Storehouse, distant 1950 ft. Similar construction and damage as the building above.

Building No. 385—Beater House, distant 1450 ft. Tile walls, wooden roof trusses. Building completely wrecked.

Building No. 475—Poacher House, distant 1400 ft. Tile walls, steel roof trusses, corrugated iron roof with concrete partition wall. This building was completely wrecked. Concrete partition wall was still standing practically intact with only a slight tilt near the top. This concrete wall was approximately 30 ft. long and at least 36 ft. high. It is 12" wide from the foundation up. This partition wall practically faced the explosive center and the fact that it was still standing in the midst of the wrecked building is a remarkable evidence of the strength of reinforced concrete.

Building No. 476—Guncotton Storehouse, distant 1650 ft. This was a small building with a concrete roof slab supported on reinforced side walls with tile curtain walls in the ends.

This building was protected by being placed in a hollow and furthermore by the standing concrete partition wall in No. 475—distant 1400 ft.—and the only damage to building was that some doors were ripped off.

Building No. 87—Ether Alcohol Building, distant 1650 ft. Comparatively high building, steel frame and corrugated iron sides and roof.

The corrugated iron was practically entirely ripped off. The steel frame was bent and twisted in places but not very badly.

Although this building appeared to be of light construction it was well braced by floors at different levels and probably the corrugated iron partly collapsed preventing a concentrated pressure on the steel frame.

Buildings Nos. 471, 472, 473, and 474. Buildings occupied by smokeless powder operation, distant 1900 ft., dehydrating, mixing and pressing. Tile buildings with steel trusses and a number of 12" concrete partition walls. The tile walls and steel trusses were completely wrecked. Concrete walls still standing and the principal equipment did not appear to be badly damaged.

Building No. 486—Refrigerating House, distant 1750 ft. Tile walls. steel roof beams supported on pilasters, concrete roof slab.

The tile walls were partly down but the concrete roof slab was practically intact. A large section of this roof slab was actually unsupported by walls which collapsed, but the slab did not break. The equipment under this roof appeared almost undamaged.

2000 To 3000 Ft. Zone

Included in this zone were buildings in immediate vicinity of No. 49, although some of them were located in the next zone.

Building No. 49—Two-story Brick Hospital Building, distant 3250 ft., with slate roof. Brick walls not seriously damaged but roof partly crushed in.

Building No. 258—Used as Quarters, distant 3450 ft. Frame building of comparatively light construction. Considerably damaged.

Buildings Nos. 44, 45, 46 and 47. Frame sheds of light construction, distant 2725 to 3000 ft. Practically entirely demolished.

Buildings Nos. 254, 255 and 256—Bag Loading Buildings, distant 3000 ft. These buildings were constructed of frame, stuccoed, with the roofs supported on rafters.

Roofs caved in and walls distorted but mostly standing.

Building No. 321—Igniter Building, distant 3050 ft. 8" tile walls. corrugated iron roof on steel lintels. Building divided by concrete barricade walls in several compartments. Building was also partly protected by a concrete barricade in front of building, this barricade being about 16' high, 18" wide at base and 9" wide at top. This barricade was originally erected as a protection for buildings 256 and 255 against building 321 and did not fully protect the building against explosions where they actually occurred. It gave evidence of the good effect of barricades.

The north end of the building which was not screened by the barricade was badly wrecked except the concrete partition walls, while the screened portion of the building was in fairly good shape. The building itself was, of course, in this case also braced by the interior concrete partition walls.

Building No. 43—Bag Loading Plant, distant 2500 ft. Part of building two-story and greater portion of building one-story. 18" brick walls, steel roof trusses, corrugated iron roof laid on steel purlins. Building had false ceiling consisting of tile arches supported between steel beams running across building. The roof had the usual slope of about one quarter in one.

This building was rather badly exposed to the explosion. The steel roof trusses collapsed and penetrated the false ceiling and the brick walls were seriously damaged.

Buildings Nos. 278—Bag Loading House, distant 2400 ft.; Store Shed

No. 42, distant 2150 ft., and No. 329—Raw Material Storage, distant 2150 ft., were frame buildings which were demolished.

Building No. 326—T.N.T. Purification Building, distant 2200 ft., No. 327—Tetryl Manufacturing Building, distant 2050 ft., and No. 328—Ammonium Picrate Purification Building, distant 2250 ft., were all three-story buildings with steel frame on concrete foundations, the concrete foundations partly forming the walls of the first floor. The columns encased in concrete and the buildings are practically similar to No. 325 described in previous zone. The interior bracing and floors were not quite as substantial as in Building No. 325 and consequently the damage to these buildings was slightly greater but the steel frames and roofs as well as the concrete foundations were mostly in good condition and a considerable portion of the equipment without serious damage.

Building No. 330—Tetryl Dry House, distant 2200 ft. One-story building, tile walls, steel rafters. At the time of the explosion this building contained 500 lbs. of tetryl in drying trays. The building was wrecked but the tetryl did not explode or burn.

Building No. 60—Storehouse, distant 2850 ft. This storehouse was of brick construction, the lower part of the wall very heavy and finished off with concrete up to a height of about 7 ft. At that level there was a stone coping running all round the building and on top of this coping the walls were lighter but provided with pilasters. On the side towards the track there were heavy concrete buttresses about 7 ft. high on each side of the three doors on the inside of the building. The building had steel roof trusses with 2" t. and g. plank sheathing and slate roof.

The roof trusses on the side towards the explosion were crushed, which in this case there was reason to believe, caused part of the side wall towards the explosion to collapse. The side wall away from the explosion and end walls were standing practically intact.

Building No. 69—Store House, distant 2900 ft. Same construction as Store House No. 60. Brick walls practically intact, roof crushed in on the side towards explosion but still carried by the standing brick walls. The roof boards shattered in places.

Building No. 70—Store House, distant 3000 ft. Same construction as No. 60 Store House. Side walls and north end wall collapsed down to top of the stone coping. Roof collapsed and completely down. South gable end standing intact.

Building No. 71—Store House, distant 3050 ft. Same construction as No. 60 Store House. This building was protected from the explosion by Building No. 70. Brick walls cracked in the north end but otherwise in fair condition. Roof trusses crushed in on the side towards explosion but the 2" roof sheathing was almost intact.

Building No. 24—Machine Shop, distant 2700 ft. 18" brick walls with pilasters, steel roof trusses and purlins. Roof sheathing consisted of 4" thick cinder concrete slab on top of the purlins. This slab covered with slate.

The effect of the explosion on this building was to almost disintegrate the concrete roof slab with the result that the immense pressure was not transmitted through the purlins to the trusses as was the case in adjoining buildings with other type of roof. Consequently, the steel trusses and purlins were still in place in almost perfect condition and the walls, not subjected to all kinds of pressures by the collapsing trusses, were practically intact.

It is interesting to note this fact and compare this building with adjoining buildings of slightly different roof construction.

Building No. 59—Store House, distant 2600 ft. 18" brick walls with pilasters, steel roof trusses and purlins, 2" wooden roof sheathing covered with slate.

In this building the roof trusses on the side towards the explosion collapsed and the side brick wall towards the explosion were completely collapsed, while the end walls and the side wall away from the explosion remained intact.

This building was of practically the same exposure as the adjoining building No. 24—Machine Shop, previously commented on. In this case the pressure exerted on the total area of the roof towards the explosion was transmitted through the 2" roof sheathing to the purlins which, together with the sheathing, held, transmitting the entire pressure to the roof trusses that collapsed and undoubtedly in collapsing kicked out one side wall in the building.

Building No. 57—Plating Shop, distant 2800 ft. 18" brick walls with pilasters, steel roof trusses and purlins, 2" wooden roof sheathing covered with slate. On the north side the roof was caved in, the steel trusses on this side badly distorted, but the 2" roof sheathing only broken in places. The outside brick walls were only slightly damaged but an interior 8" tile partition wall collapsed.

Building No. 58—Component Parts Shops, distant 2700 ft. Practically same construction as No. 57.

Building was originally a storehouse and the roof trusses were of the usual design, supposedly only strong enough to withstand ordinary snow load and wind pressure. In installing the equipment in this shop the transmission was not carried on the trusses which were probably too light for the purpose, but heavy iron beams were placed at intervals across the building and anchored in the brick walls and the shafting hung from these beams. This additional bracing held the building walls in perfect alignment and to

put this building in operation, only a very small amount of work was necessary in lining up the shafting.

The roof on the other hand was in the usual condition with the roof trusses crushed in on the side towards the explosion, but as usual the 2" roof sheathing held almost intact.

Building No. 30—Carpenter Shop, distant 2600 ft. Brick walls, steel trusses and purlins with corrugated iron roofing. This building had a false ceiling consisting of tile arches supported on I beams running across the building. These I beams also supported on one row of columns in the center of the building.

This building was in a rather exposed position but the principal damage was to the roof which was crushed in on the side towards the explosion, causing the trusses to collapse, but the ceiling I beams braced the walls from the inside and the brick walls were practically intact. The collapsing trusses in a few places penetrated the tile ceiling but did not cause any damage except at the point of penetration and most of the ceiling was in perfect condition.

It can be concluded from the effects on this building as well as by similar effect on other similar buildings, that the pressure exerted on the corrugated iron roofing, which was only supported on the purlins with no sheathing between, was transmitted to the purlins which held and further to the trusses which collapsed.

Building No. 386—Change House, distant 2700 ft. This was a tile building, which was practically wrecked.

Building No. 65—Ice House, distant 2450 ft. Frame Building. Wrecked. In this vicinity were located the pyrotechnic buildings, mostly small buildings of frame construction, which were more or less wrecked.

Building No. 106—Solvent Recovery House, distant 2000 ft. One-story brick building with brick partition walls, 1½" t. and g. roofing boards on wooden rafters, corrugated iron roof. The roof was shattered, but brick walls only cracked in places.

Building No. 312—Solvent Recovery Office, distant 2100 ft. Frame and corrugated iron building, completely wrecked.

Building No. 114—Tray Dry House, distant 2050 ft. Frame building covered with corrugated iron, lined inside.

Building was wrecked but not entirely demolished, the interior partitions bracing the building.

Building No. 122—Powder Dry House, distant 2300 ft. Same construction as building No. 114 but a larger area and less protected by trees.

Building wrecked to a greater degree than building No. 114.

Building No. 125—Powder Dry House, distant 2550 ft. Same construction at No. 114. Damaged the same as 122.

Building No. 90—Powder Dry House, distant 2550 ft. Same construction as building No. 114. Building badly distorted but not entirely wrecked.

Building No. 120—Small Arms Powder Dry House, distant 2350 ft. Tile walls, stuccoed, tile partition walls, corrugated iron roof on steel purlins. Roof demolished, walls partly collapsed.

Buildings Nos. 290 and 291—Blending Houses, distant 2750 ft. Frame covered with corrugated iron. Corrugated iron partly torn off and framework was badly twisted.

Building No. 115—Vapor Dry House, distant 2850 ft. Frame and corrugated iron construction. Very light frame. Roof crushed in and parts of walls down.

3000 FT. TO 4000 FT. ZONE

Building No. 72—Storehouse, distant 3200 ft. Same construction as building No. 60 described in previous zone. Side walls and north end wall collapsed down to top of coping. Roof collapsed and completely down. South gable end standing intact.

Building No. 20—Shop Building, distant 3300 ft. Brick walls, steel roof trusses and purlins, corrugated iron roof. Building had a false ceiling of tile arches supported on I beams running across the building.

Walls were practically intact, being held together by the cross I beams supporting the tile ceiling. Roof was caved in on the side towards explosion. Roof trusses collapsed and partly penetrated the tile ceiling which, except for these penetrations, remained in good condition.

Building No. 469—Pump House, distant 4375 ft. Small reinforced concrete building, practically undamaged.

Building No. 381—Frame Shed over Sewage Disposal Plant, distant 3400 ft. Wooden frame shed completely wrecked.

Building No. 61—Shell Machine Shop, distant 3800 ft. 18" brick walls and pilasters, steel roof trusses and purlins, 2" wooden roof sheathing covered with slate. Walls intact, roof trusses only slightly bent, roof sheathing good except opened up at ridge. The slight damage to the roof could be explained by the fact that this building did not face squarely against the site of explosion.

Buildings Nos. 62 and 63—Shops, distant 3850 ft. and 4100 ft. Same construction and, if anything, less damaged than building No. 61.

Building No. 418—Frame Shed, distant 4000 ft. Of light construction, completely wrecked.

Buildings Nos. 316 and 317—Large light steel frame buildings, dis-

tant 3300 ft. With steel sheathing. Both buildings were almost completely wrecked.

Building No. 19—Hydraulic Pumping Station, distant 4000 ft. This was a brick building which evidently at one time was divided by a number of brick partition walls with steel purlins extending between partition walls carrying a corrugated iron roof. Later these partition walls were torn down up to the square of the building and heavy cross I beams carried the still remaining upper portion of the brick walls in which the purlins rest with a row of columns in the center of the building supporting the cross I beams. Except for some slight bulges in the roof building was practically undamaged.

Building No. 52—Ammunition Assembly Building, distant 3725 ft. Brick walls, steel roof trusses and purlins, slate roof on planks. Roof trusses distorted and roof settled down on site towards explosion. Otherwise building was not damaged.

Building No. 117—T.N.T. Casting Building, distant 2300 ft. This large building was constructed with a concrete frame and numerous concrete partitions. Tile walls stuccoed, steel roof trusses and purlins, asbestos protected corrugated roofing.

Outside of broken glass and some of the roofing ripped off, this building was in very good condition, undoubtedly due to the reinforced concrete frame and partition walls.

Building No. 27—Booster Building, distant 3750 ft. Brick walls, steel roof trusses and purlins with corrugated iron roof supported on I beams running across the building, which I beams were supported on a center row of columns.

The roof crushed in places, trusses distorted and in some places penetrating the tile ceiling which, however, was not seriously damaged. Building walls were in good condition.

Buildings Nos. 208 and 209—Explosives Dry Houses, distant 3800 ft. Tile buildings with steel girders carried on the tile walls, steel purlins, corrugated iron roof. Wall towards explosion blown in and building wrecked.

In this zone east of Picatinny Lake the following buildings are worth commenting on:

Building No. 96—Testing Galleries, distant 3200 ft., Building No. 298—Photographers building, distant 3200 ft., Building No. 140—Store House, distant 3450 ft., Building No. 142—Ballistic Laboratory, distant 3650 ft. All tile buildings with corrugated iron roof on wooden rafters, 8" tile walls. All of these buildings collapsed completely.

Building No. 133—N. C. Dry House, distant 2100 ft. Two-story building, hollow tile walls, stuccoed, interior partition, wooden rafters, corrugated iron roof.

The roof was crushed in but the walls were almost intact. The light damage was probably due to topography and trees screening this building.

OUTSIDE OF 4000 FT. ZONE

Substantial buildings in this zone such as officer's quarters, No. 102, distant 4600 ft., No. 103, distant 4300 ft., and No. 2, distant 4000 ft., and a barn, No. 5, distant 4875 ft., suffered practically no damage except broken windows, plaster, etc. The Garage, No. 285, distant 4800 ft., was a large one-story building with steel frame supported on interior steel columns, tile walls and a flat roof carried on steel purlins. This building was also practically intact due to the strengthening steel frame construction and flat type of roof.

Among other buildings in the extreme south area were about twenty-five tile storehouses, distant 5100 ft. to 7500 ft., with 8" tile walls, the roof supported on wooden rafters. Almost without exception these buildings were damaged to the extent of sloping roofs being bulged in on the side towards the explosion and frequently some portion of the tile walls collapsing.

The same thing applies to about 50 buildings, distant 3650 ft. to 8700 ft., in the extreme western portion of the arsenal. These are mostly small buildings about 30' x 30' constructed of 8" tile walls with corrugated iron roof laid on wooden rafters extending the length of the building. All roofs were bulged in on the side towards the explosion sometimes completely collapsing and portions of the tile walls were down. A few of these buildings that were used for manufacturing purposes were provided with interior partitions and in such cases the building withstood the shock much better.

The structural damage done in the various buildings of Picatinny Arsenal depended upon:

- The distance from the site of the explosions.

- The structural strength of the building itself.

- The extent to which the individual buildings were screened or otherwise protected from the effects of the explosion.

The buildings of Picatinny Arsenal were in a general way, of a good and substantial construction. The first buildings were erected about the year 1883 and erection of buildings had been more or less continuous.

The effects of the explosion showed positively that the peaked type of roof was the weakest part of the buildings. The principal buildings located within the inner zones with peaked roofs were almost entirely constructed with steel roof trusses and purlins and roof covering of various kinds.

While no actual dimensions were taken of the roof trusses, they appeared to be of the ordinary strength and spacing, probably designed to withstand a maximum wind velocity of 100 miles per hour, which with

most of the roofs having $\frac{1}{4}$ pitch would be equivalent to a perpendicular pressure of about 24 lbs. per sq. ft. This would apply to a wind storm where it can be assumed that the force is exerted in a practically horizontal plane. This was not the case with the explosive wave in this instance. The exploding magazines were located above the zone of principal damage. The explosive wave that struck the buildings was therefore not horizontal but approached at a right angle to the sloping roof. The wave velocity varied but in some areas undoubtedly exceeded 100 miles per hour. Even a 100 mile per hour gale striking the roof in the direction it did would have created a pressure of 50 to 60 lbs. per square foot.

Many of the buildings gave evidence that, even with a roof truss that could not withstand the pressure and collapsed, the building walls were immensely strengthened by having substantial beams running across the building from wall to wall. This construction in many instances saved the walls of buildings in which the roof trusses collapsed. The steel frame flat roof buildings such as 325, 326, 327 and 328, showed remarkable strength, particularly when the interior was well braced by beams, supporting floors and to a noticeable extent, by concrete floors at the different levels as compared with wooden floors laid on steel girders.

The strength of reinforced concrete to resist such shock and pressure as here occurred was shown as remarkable. The flat concrete roof of the power house, building No. 514, undoubtedly saved a large portion of the walls in this building from collapse. The high concrete partition wall in building No. 475 has already been commented on as has the concrete building No. 476 and the concrete partition walls in buildings 472, 473, 474 as well as the concrete roof in building 486. All of these buildings were in comparative vicinity of the explosions.

For structural strength substantial brick walls appear to be the choice next to reinforced concrete. Many of these walls that were still standing had been subjected to tremendous shock and pressure. They have been referred to in the detailed description and here will only be mentioned buildings 118, 54 and 108 which were directly exposed and in comparatively close vicinity to the explosions. All of the roofs of these buildings were down and the walls of No. 118—Main Office Building—were completely down on the side towards the explosion, but the three story gable end wall away from the explosion was still standing, as were also almost intact, walls of buildings 54 and 108.

Building No. 38 which was not only greatly exposed to the explosion, but caught on fire, still had one gable end wall standing and portions of the other walls.

Light structural steel buildings of the unit knock-down type, such as

buildings 316 and 317, were absolutely valueless under shock and pressure as here occurred.

A great number of tile buildings existed at Picatinny as well as in the Naval Department; most of them built of 8" tile, many with wooden rafters carried on the tile walls. (This construction applied mostly to Picatinny). Others with steel girder roof construction supported on pilasters. (This occurred mostly in the Naval Depot). The light tile walls did not have sufficient structural strength to withstand the shock and the action of the collapsing roof. On the other hand, the tile ceiling arches in some of the buildings at Picatinny showed excellent results, being strengthened by the steel beams carrying the arches spaced comparatively close together. For the purpose of curtain walls or similar walls in a substantial structural steel or reinforced concrete frame building, tile may be used but it should not be placed in long or high span walls and never be depended upon in those circumstances for structural strength.

DAMAGE TO OUTSIDE PROPERTY

On the road from the entrance into Picatinny Arsenal (Cannon Gate) to Spicertown, there were 14 or more small frame houses, spread out for a distance of about one mile; the first being about 1½ miles from the scene of the explosions. None of these houses suffered any damage, other than the knocking down of plaster, the breaking of a few windows, and a door or two pulled out. In Spicertown, a distance of about 2½ miles, and Wharton, about 3 miles away, there was practically no damage at all; in fact, in this direction (SW) there was no damage outside of an occasional pane of glass being broken.

Located in a corner of the Lake Denmark Depot were three frame houses and some frame out-buildings—distant about 2500 to 2700 feet—all of which had roofs stove in, and those of flimsy construction collapsing.

Further along the road were five or six fairly well constructed frame residences and bungalows. All of these had upper portions of the houses pulled out and roof supports damaged.

Near the crossroad (distant about 3500 feet) were a few more frame dwellings and a small frame church. The dwellings had the roofs damaged and some siding pulled loose. The church did not suffer any marked external damage but was considerably ripped to pieces inside.

On the road from Picatinny to Mt. Hope (between Picatinny and the crossroad) there were two or three frame farm houses and barns, also a few dwellings and a collection of bungalows. All of these had the roofs seriously damaged, porches pulled loose and sidings damaged. Some of the flimsy structures were about wrecked. The above were about 3000 feet away from the explosions.

Beyond the crossroad and into Mt. Hope, there were a collection of cheap frame dwellings (distant about 4500 feet) more or less sheltered by a hill. A few broken rafters, windows and doors pulled loose, was the extent of the damage suffered.

On the crest of the hill above Mt. Hope, about 5800 ft. distant, there were three or four frame dwellings, one of which in a more exposed position had the roof supports and coverings damaged to the extent that renewal was necessary. The others were not damaged except plaster knocked down and windows and doors pulled loose.

Down the hill, and at the foot of the hill, lay Mt. Hope (distant about 6000 feet), a small village containing a store, garage, and collection of frame dwellings, also a well built stone residence. No damage of moment occurred here. Damage to plaster and glass breakage was slight.

In the town of Rockaway, a distance of about $3\frac{1}{2}$ miles, the glass breakage was quite general. Practically all plate glass windows in the business section were broken, considerable of the window panes in residences were broken, and two or three churches nearly all windows were broken and the frames in some instances pulled out.

There was a row of cheap frame houses in the lower end of the town, probably 4 miles away from the explosion, which had the roofs slightly damaged and some chimneys knocked down. Some of the windows were ripped out.

Beach Glen (distant about $3\frac{3}{4}$ miles). This village consisted of a small group of frame houses and barns. The damage consisted of plaster knocked down and some breakage of glass.

Hibernia (distant about $3\frac{1}{4}$ miles). This village consisted of a group of cheap frame structures, with a few better grade frame residences and a frame church. The damage consisted principally of some plaster knocked down and the breakage of glass. In one end of the settlement, nearest to the point of explosion, the damage to plaster was fairly general, and some doors and windows pulled out. Quite a number of people were slightly cut by flying glass, and one child injured by bricks from a falling chimney. This section was evacuated after the first and second explosions.

On the road from Hibernia to Lake Denmark ($1\frac{3}{4}$ miles) there were a few frame dwellings and barns, all of which had plaster damaged and windows and doors ripped out. One house, a cheap two-story frame, which was in plain sight of the water tower on the northeast section of the Lake Denmark Reservation, had plaster knocked down and doors and windows ripped out. The people residing in the house were not injured. A ramshackle frame barn located on the same property had the sides pulled loose.

Further up this road, at the corner of the Naval Reservation was a

frame two-story house, old and in poor repair. This house had plaster knocked down and some of the windows and doors pulled loose.

At Denmark (about 2 miles away) there was a collection of four or five houses, the principal one a two-story frame residence comparatively new and good type of construction. The windows and doors were pulled out, some damage done to plaster, and one chimney top knocked down.

Across a valley to the northeast, situated on the crest of a hill about $2\frac{1}{4}$ miles away, in plain view of the water tower on the Navy Reservation, there were scattered groups of houses, mostly frame bungalows. Some damage of a minor nature was experienced by most of these houses. A two-story frame cottage was badly wrenched and the sides of the house being separated from the floors; roof rafters were cracked, chimney knocked down, some of the doors and windows pulled loose. There were two people in the house at the time of the first explosion; the woman received a few slight scratches from flying glass. One bungalow in this community was slightly shifted on the foundation. In this vicinity it was reported that there were a number of persons who received cuts from flying glass.

KILLED AND INJURED

Nineteen casualties were caused by the detonations. The greatest loss of life occurred in the fire fighting parties in the vicinity of Temporary Storehouses Nos. 8 and 9. Eleven marines and one enlisted man of the Navy, and four commissioned officers, (three of the Navy and one of the Marine Corps attached at the station) were killed at this point. Most of the men killed were in the first fire-fighting party to arrive at the scene, and were probably all within 300 to 500 feet of the explosion.

Thirty-eight officers and privates in the Navy Marine Corps were injured (34 lacerations and bruises, 1 sprained back and shock, 1 wounded by shell fragment, 1 fractured skull, 1 shock).

Of the 38 injured, about 25 were with the second fire-fighting party which, with a hose cart, had reached a point near Store House No. 1 (within 1000 ft. from Temporary Store House No. 8), when the first explosion occurred; the force of the explosion disorganized the party, and by the time they got started again with the hose cart, the second explosion occurred. (Orders were then given to abandon the post).

The body of a woman was found under the ruins of the two-story stucco dwelling which stood about 300 ft. from Temporary Store Houses Nos. 8 and 9. The body was in the basement under a mound of ashes and debris, and apparently she had survived the first explosion and had taken refuge in the basement when the second explosion occurred, which completely demolished the building.

Having been warned by the fire, the wives and families of the Lake

Denmark Depot employees (who resided in dwellings near to Temporary Store Houses Nos. 8 and 9), together with some visitors (in all 1 man, 3 or 4 women, and 2 children—one a baby 18 months old), hastened down the road in the direction of Picatinny Arsenal, and were a short distance outside of the Lake Denmark gate (about 750 ft. from Temporary Store House No. 8 and 600 ft. from Temporary Store House No. 9) when the first explosion occurred. An automobile, with 4 men passengers, passing about this time, stopped and took aboard the women with the baby, and the second explosion immediately followed. The people on foot were knocked down by the explosion and all received injuries, principally laceration of faces and arms. The passengers in the automobile, which was wrecked, were thrown out and one woman was so badly injured by flying debris that she died in the hospital later. The baby received lacerations of the scalp, two of the men lacerations and cuts on the face, one lacerations about the arms, and the other slight injuries.

The Commander of the Arsenal and a private were at Temporary Store House No. 3 (about 600 ft. from Temporary Magazine No. 8) at the time of the first explosion. Both were badly shocked and injured by flying debris, but managed to remain on duty in the upper end of the Lake Denmark Depot most of the night following the disaster. A civilian employee was in contact with the Commander of the Depot during the disaster, and received quite serious injuries from flying debris, etc.

An officer, a member of the Picatinny Arsenal Staff, was killed in the Beater House on Picatinny Arsenal by being crushed when the building collapsed. This house was located about 1500 ft. away from the first explosion and it seems logical to assume that the collapse of the building was due to the first explosion, since otherwise he would have left the building before the second explosion.

The Gatekeeper, or Guard, stationed in the Time Office on Picatinny Arsenal, a little over 2100 ft. from Temporary Store Houses Nos. 8 and 9, had some ribs broken and suffered other injuries. The watchman, or Guard, in the Main Office on Picatinny Arsenal (distant about 1500 ft. from Temporary Store Houses Nos. 8 and 9) was caught under falling debris, caused by the first explosion, but managed to free himself, climb out a window, and had run down the road about 300 ft. to a point opposite the Millwright Shop, when the second explosion occurred, by which he was knocked down and rolled. His injuries consisted of only cuts and bruises.

There were men on duty in both the Power House on Lake Denmark Depot and also the Power House on Picatinny Arsenal. These men re-

mained on duty until after the second explosion, when they left the buildings to seek a place of safety. None of them received injuries of any moment.

Some of the personnel and members of families on Picatinny Arsenal received slight injuries, principally from flying glass. Two or three who were in the vicinity of the Main Office in an automobile were struck by missiles (stones) thrown by the two first explosions. The hits were not direct, but by recochetting stones which had struck the road and ground between them and the scene of the explosion.

A couple of employees of the Lake Denmark Depot resided in small frame dwellings in the south end of the Reservation. These houses were about 2000 ft. from Shell House No. 22 and 2700 ft. from Temporary Store Houses Nos. 8 and 9. The adults and children, some 7 or 8 in all, received slight injuries principally from the shattering and collapsing of the dwellings.

MISSILES

The ground between Temporary Magazines Nos. 8 and 9, to a point beyond the Main Office of Picatinny Arsenal, was covered with boulders and rocks, the limits of this zone reaching 2000 ft.

Scattered over the reservation could be found pieces of the trusses and girders which supported the roofs of Temporary Store Houses Nos. 8 and 9, and Shell Store House No. 22. These fragments, deeply pitted, were scattered in many directions, a large number being found on the top of the hill in the vicinity of the Commander's Residence on Lake Denmark Depot. Some few pieces were found on Picatinny Arsenal. These pieces varied in weight from a few pounds up to more than 100 pounds, and were thrown about 3000 to 4000 feet.

Strewn over the area in the vicinity of Shell Store House No. 22 were many shell of various calibers, a few of which had exploded with a low order of detonation. There were shell fragments found in the vicinity of No. 77 Boiling Tub House on Picatinny Arsenal, and also of 96 Testing Gallery, Picatinny Arsenal (thrown about a mile.).

There were a few unexploded shell found as far away as $\frac{3}{4}$ of a mile.

There was a crater from the explosion of a 5" shell in the Parade Ground of Picatinny Arsenal (about one mile from Shell House No. 22). There was also a crater from an exploded shell alongside the road from Picatinny Arsenal to Mt. Hope (3000 ft. away), and undoubtedly many similar instances would have been disclosed by close search of the adjacent country.

Many shells were found in quite badly damaged condition, and it was surprising that they had not exploded. The tabulation shown below summarizes the results of this explosion:

SUMMARY

	Totally Demolished or Collapsed	Partly Demolished or Collapsed	Substantial Structural Damage	Minor Structural Damage
BUILDINGS				
Substantial Construction	1500 ft.	3000 ft.	4000 ft.	—
Hollow Tile	4000 ft.	5000 ft.	7000 ft.	8000 ft.
Frame	3000 ft.	—	4800 ft.	—
DWELLINGS				
Substantial Construction	—	—	4000 ft.	4500 ft.
Stucco-Frame, etc.	—	3000 ft.	4500 ft.	*2¼ miles

*Some small frame houses on exposed hilltop—the damage verging on substantial structural.

NOTE:—Plaster knocked down, doors and windows damaged, up to about 3 to 4 miles.

GLASS BREAKAGE

	General	Slight
Plate.....	Up to 3½ miles	Up to 5 miles
Window.....	Up to 3½ miles	Up to 5 miles

KILLED AND INJURED

	Killed	Injured	Escaped
In Buildings.....	1500 ft.	**3 miles	Within 1500 ft.
In Open.....	***600-750 ft.	***750-1500 ft.	Within 750 ft.
**Cuts from glass.			
***Struck by missiles			

The American Table of Distance has only been detailed or charted up to a quantity of 1,000,000 pounds. To make comparison with the damage resulting from this explosion, it is necessary for an amount of 1,600,000 pounds to extend the table by calculation. The barricaded and unbarricaded distances would be approximately as follows:

1,600,000 Pounds	Barricaded	Unbarricaded
To nearest inhabited dwellings.....	4100 ft.	8200 ft.
To nearest public railroad.....	2350 ft.	4700 ft.
To nearest public highway.....	1200 ft.	2400 ft.

It will be noted that 8200 feet for an unbarricaded magazine would have been ample protection for buildings of any construction, even though there was a weakening effect on structures by the first explosion of 670,000 pounds. The trees surrounding Temporary Store Houses Nos. 8 and 9, might be considered as constituting a barricade, but the explosion in No. 8 building practically removed it, leaving the explosion in No. 9 a clean sweep.

Undoubtedly 4700 feet would have been ample protection for a railroad, and from the experience of persons in the open, 2400 feet was more than sufficient protection for a highway.

MANILA, P. I.

About 3 o'clock on Sunday afternoon, October 11th, 1924, there was an explosion in a magazine belonging to the Bureau of Public Works of Manila. The magazine was situated on Talim Island in Laguna de Bay, an isolated position about 40 miles southeast of Manila. It had been the site of the arsenal of the Filipinos during the revolution, and many war prisoners had been kept there. It took four hours by launch from Manila, up the Pasig River, to reach the island.

On the northern part of the island there were government stone quarries, from which rocks were obtained for provincial roads on Luzon. To the south was the government reservation, occupying about one-third of the island, where the magazine stood. There was a small village of a few hundred people about 1500 feet from the magazine, protected by a hill 200 feet high.

The magazine was 150 feet long by 50 feet wide. It was built of concrete with a sheet iron roof, and a yale-locked door at each end.

The following explosives were stored in the magazine:

	T. N. T.	Dynamite	Black Powder	Miscellaneous Explosives
From Commercial Firms.....	4,700 lbs.	267,700 lbs.	3,375 lbs.	
From Bureau of Public Works.	50,000 lbs.		20,000 lbs.	
From Bureau of Constabulary (Confiscated stores).....				500 lbs.
Total quantity of explosives.....	54,700 lbs.	267,700 lbs.	23,375 lbs.	500 lbs.
				346,275 lbs.

In addition to this, there were stored in the magazine 305,781 detonators in boxes, 47,066 electric detonators in boxes, making a total of 352,851 detonators, as well as some loose caps among the confiscated stores belonging to the constabulary bureau. There were also 14 sacks of "red fire" powder, containing strontium nitrate, sulphur, etc. The government T.N.T. and Black Powder were stored in open kerosene cases and barrels.

An aisle ran through the building from door to door. On one side were stored explosives and detonators in the following order: First, kegs of blasting powder, and detonators, then a long space devoted to dynamite, then a quantity of T.N.T., more dynamite, electric detonators and fuse. On the other side of the aisle were stored, first dynamite, then a quantity of fuse, blasting powder and electric detonators; next, a large quantity of dynamite; then the confiscated explosives, largely dynamite, belonging to the constabulary bureau, and then the bulk of the T.N.T.

Under any circumstances, the combination of T.N.T., black powder, dynamite, red fire powder stored with detonators in one building would be dangerous enough; but the storage arrangements in this magazine, prac-

tically providing each store of explosives with a supply of detonators, presented perfect conditions for an explosion from various causes.

When the explosion occurred, about 3 P. M. on Sunday, only two persons were in the vicinity of the magazine, two soldiers in the constabulary guard house, about 300 feet away. Both of them were killed. One was struck by a large stone on the side of the head, while the other was killed by concussion, receiving only a few minor wounds.

No one else was killed. A game of indoor baseball was in progress at the barrio, and here all the village people had congregated. With them were five of the seven soldiers stationed on the island, and the caretaker of the magazine, his wife and children. Had these people been in their own houses, no doubt they would have been killed by the explosion. The barrio, about 1800 feet from the magazine, suffered more or less slight damages from the debris which was thrown in the air and went through the roofs and sides of the houses. A few persons received slight wounds from flying debris.

The barracks of the constabulary guard and the caretaker's house, about 300 feet from the magazine, were entirely destroyed.

The village, about 1500 feet away, consisted of bamboo and nipa houses which were not in good condition at the time of the explosion. Practically the only damage done was to one small house with four wooden walls and a galvanized iron roof. The front of this house was blown out for about one inch.

Nothing remained of the magazine. On the site were two craters, about 120 and 60 feet in diameter and 12 feet deep. There was a distinct ridge between the two, as though two explosions had taken place. Thousands of feet of fuse were found several hundred feet from the place where the magazine had stood. Much of this was hanging in the trees, and some of it had not been burned. The ground around the scene was strewn with debris, trees and shrubbery.

Of the stock in the magazine, everything was destroyed with the exception of the double tape fuse, and 3 of the sacks of red fire in the magazine, which were found after the explosion on the ground at the opposite side of the warehouse from where they had been stored.

About 150 feet back of the powder magazine was a cornfield, about 300 feet long. The corn nearest the magazine was laid flat, but the other end of the field was not damaged.

The cause of the explosion was never known. It was not caused by lightning, as it was a fair day. If it had been caused by fire, from outside, the two soldiers in the constabulary guard house would in all probability have seen the smoke, and escaped. Without doubt, the explosion originated inside the magazine.

The slight damage done by this explosion makes it of no value in measuring structural damage done at varying distances.

MINDI MAGAZINE, CANAL ZONE

The Mindi powder and dynamite magazine maintained by the government, situated at a point near the Gatun-Colon wagon road, five miles from Colon and two miles from Gatun, was destroyed by an explosion at 9.20 A. M. on Sunday, July 5th, 1914. It contained 210,875 pounds of 45% dynamite, and 15,394 pounds of 45% and 60% Trojan powder, making a total of 450,919 pounds of explosives.

The magazine was built in 1908 on a site carefully chosen a mile and a half southwest of the Mindi Spur. It was surrounded by a number of hills which served as a protection to the nearby villages, and built into the side of a hill facing in the opposite direction. Hollow concrete blocks, 12 inches thick and bullet proof, were used for the walls, and the roof was concrete reinforced with old Belgian rails, and waterproofed. The magazine was 112 feet long, 48 feet wide, and 9 feet high inside. The concrete roof kept the interior dry and cool. Ventilation was provided by air flues which opened under the roof.

Near by, and yet far enough away so that an explosion in one magazine would not affect the other, was a small detonator house, 33 feet long, 17 feet wide and 10 feet high, built of concrete blocks with a ceiling of reinforced concrete, with a corrugated iron roof above it.

The night watchman, a black Barbadian, lived in a small house about 600 feet from the magazine with his wife and family of six children. On the morning of the fifth of July, his son noticed smoke coming over the crest of the hill nearest the magazine. The night watchman and his family started for a place of safety, and had gone about 100 feet when the explosion occurred, at 9.20 A. M. They all escaped uninjured except one child who sustained a minor scalp wound from a falling stone.

The body of the day watchman was found about 200 feet northwest of the magazine. In examining the ground, several fragments of clothing were found about twenty feet nearer the building than the point where he lay, which indicated that at the time of the explosion he was in all probability close to the building. The puncture wounds on his body appeared to be caused by very small fragments of the concrete blocks of which the magazine building was constructed. It was thought that the man was probably running away from the building and at the moment of the explosion was in slight depression of the ground which protected the lower half of his body from the maximum force of the blast.

The shock was strongly felt in Mount Hope, Colon, Gatun and con-

tiguous territory, but no damage was done except to broken window glass. The blast tore a hole in the earth where the magazine stood, and deposited the material from it, and from the adjoining side of the hill in a mound in front about 12 to 15 feet high. The bed of the Mindi River nearby was filled to a height of from 10 to 12 feet, the barrier completely damming the stream and causing it to seek a new course.

Structural damage was limited to the watchman's house 600 feet from the explosion, a small frame building which collapsed and was broken into small pieces; and the small detonator house, 450 feet away, which was wrecked. The wall nearest the explosion was drawn out, and the roof fell in, but the stock of caps and fuzes stored there was uninjured. There were no other buildings in the neighborhood by which to measure damage from this quantity of explosive.

The cause of the explosion was considered to be spontaneous combustion from the lack of any other reason. The dynamite was not old, the watchman was a reliable man never known to smoke near the building, the condition of his body proved that he was not in the building at the time to have detonated the dynamite by knocking over a box or other carelessness, and there was no motive to induce any malice. It was a perfectly clear day, and no lightning flashes had occurred.

The magazine was so well located and barricaded by its position under the hillside, that the towns of Colon Cristobal and Gatun escaped injury, except broken glass. Windows were broken to a distance of four miles, and missiles were thrown 2400 feet. The railroad rails used as roof reinforcements in the magazine were thrown for considerable distances, in one instance for about a mile and a half.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Small concrete magazine	Hillside	Wrecked	600
Area of structural damage.....			No buildings to measure
Missiles thrown.....			1½ miles
Glass broken, up to.....			4 miles

MORGAN PLANT, NEW JERSEY

At 7.30 P. M. on October 4th, 1918, an explosion originating in an amatol kettle in one of the shell loading units of the Morgan Plant near Perth Amboy, New Jersey, was communicated by fires and explosions from one building to another, completely wrecking the plant.

The United States Government secured the land for this plant during the war, and the T. A. Gillespie Company contracted to build the plant and operate it. Work was begun on construction early in 1918. Explosives experts advised as to its location and construction.

The works were situated two miles south of Perth Amboy, on a reservation of land containing 1300 acres. The conformation of the ground was hilly towards the north, and low, marshy country towards the south, where it bordered on Cheesequake Creek. The plant could be reached by lighters up this stream, which flows into the Kill von Kull back of Staten Island, and by this means ammunition could be directly shipped abroad. Six railroads were also easily accessible, and the convenience of the location for receiving construction materials and supplies and for shipping the loaded shell was a reason for choosing the site.

The sandy soil of New Jersey made construction work easy, and the hills to the north provided some natural protection to the magazines.

The layout of the plant was as follows:

The administration buildings and barracks were built on high ground to the northeast, facing on the Morgan Road.

The 13 shell loading units, of which 7 were operating at the time of the explosion, were built in hilly country to the northwest.

The 41 main storage magazines were built in isolated positions to the south, along Cheesequake Creek.

New storage warehouses, located on a plot of 600 acres acquired later, were built to the west beyond the operating units.

In addition, there were power, heating, police, fire, storage and railroad buildings on the plant.

To fence in the operating part of the plant and the main storage magazines required 8 miles of fencing, and within the limits of the plant there were about 40 miles of railroad tracks.

Each shell loading unit was a complete plant in itself and consisted of a main loading building, empty shell storage, service magazine for T.N.T., service magazine for ammonium nitrate, an office, change houses and lavatories, fan, supply and exhaust houses, fume exhaust house, electrical control switch house, and a shell hospital.

The average distance separating units was 110 to 265 feet between the surrounding wire fences, and from 425 to 500 feet between loading buildings. The T.N.T. storage magazines were at least 700 feet from any operating unit and 1200 feet from the magazines for finished rounds.

The construction of the plant buildings was as follows:

The administration buildings and barracks were of frame construction with rubberoid roofing.

The operating buildings of the loading section were of wood frame con-

struction, post foundations, galvanized iron roofs and sides. The roof trusses were painted with fireproof acid-resisting paint. The floors were a special concrete.

The operations in these buildings were conducted on the ground floor, with the exception of the melting and mixing room which was on the second floor just over the pouring room. The melting kettles were separated by brick fire-walls, which extended down to the pouring room below, dividing it into bays. Next to the kettle room was a vacant space used for the temporary storage of amatol waste or scrap. The loading section was also separated from the rest of the building by brick fire-walls.

The T.N.T. storage and service magazines had post foundations and were constructed of wood frame, with galvanized corrugated iron roofs and siding. The interior was painted with fireproof acid resisting paint. The floors were concrete. These magazines were surrounded by timber earth-filled bulkheads four feet wide at the top and from six to ten feet wide at the base. Each of these magazines held 150,000 pounds of T.N.T.

The ammonium nitrate storage buildings had brick foundations and brick side walls 8 feet high; wood frame roof trusses, covered with asbestos roofing, concrete floors, and all exposed timber painted with acid resisting paint. These buildings were used for both service and storage. Their dimensions were 50 x 300 feet.

The storage buildings for component parts and completed rounds were of wood frame construction with wooden floors. The walls and roof were covered with corrugated galvanized iron. They were 50 feet wide and 500 feet long, with one exception, which was 1000 feet long, divided in the middle by a brick fire-wall.

The shell hospital was an L-shaped building, the main part of which was about 10 x 25 feet, had a concrete floor, wooden studdings, corrugated iron sides and roof. The long part of the L connected the hospital with the operating unit.

The number of workmen employed on the plant at the time of the explosion was about 8,300. Of these men, about half were working on construction, and the other half were operating the seven shell loading units. The employees were of all nationalities.

There was an organized fire-fighting outfit on continuous duty on the plant, consisting of a chief, three captains and thirty firemen.

Upon the entry of the United States into the war, amatol was adopted for loading high explosive shell, following the English practice. Amatol consists of a mixture of T.N.T. and nitrate of ammonia, used in the proportion of 20 parts of T.N.T. to 80 parts of nitrate of ammonia, or in a 50-50 proportion.

The T.N.T. received at the plant was stored in magazines built around

a hill facing the meadows at Cheesequake Creek. Sufficient T.N.T. for the daily needs of the operating unit was kept in a T.N.T. service magazine attached to each unit. Not more than two days' supply was supposed to be kept in these service magazines, but because of the great quantities shipped to the plant, there was more than two days' supply in the service magazines on the night of the explosion. The difficulty in obtaining information as to shipments in any reasonable length of time in advance of their arrival was the cause of this condition.

Ammonium nitrate was not considered as an explosive, and 45 days' supply was carried in storage in the service magazines attached to each unit.

Taking the operations in No. 6-1, the shell loading unit in which the explosion originated, as representative of the operations in all the units, the five different departments were as follows: Cleaning and shellacing of empty shell; preparation of explosives and mixing of amatol; loading department where pouring was done; topping department; and painting, weighing and shipping department. Each department was under a foreman, who was in turn under the superintendent of the unit during the day, or one of the assistant superintendents of the unit during the night. The maintenance and upkeep of the equipment was taken care of by two mechanics, one oiler, one steam fitter, and one electrician.

The preparation of the explosive consisted of three operations; first, crushing the ammonium nitrate; second, the drying of the ammonium nitrate, and third, the loading of the T.N.T., amatol scrap and ammonium nitrate into the kettle.

Ammonium nitrate was taken from the storage building and hauled in cars up an incline to the second floor of the dryer building, where it was first passed through a rotary crusher and then into a dryer. In passing out of the dryer, the material went through a 12 mesh-to-the-inch sieve into a galvanized ash can in which it was carried to the kettle room.

T.N.T. was brought from the service magazine in one hundred pound boxes, which for some two weeks prior to the explosion had been opened with copper chisels and hammers in the corridors outside the service magazine. The T.N.T. was weighed and then examined for foreign matter by the workmen, either by running their hands through it or poking it with a stick. No screens were used. Twelve hundred pounds of T.N.T. was then loaded from the boxes into the kettle with scoops, although at times it appears that it was dumped into the kettle directly from the boxes. The T.N.T. was heated until it became molten and had reached a temperature of 92°C. Two hundred pounds of amatol scrap was then added to the mixture. Only clean amatol scrap was supposed to be used; namely that obtained from the inside of pouring pails or from the split shell. This scrap was carried to the kettle room in T.N.T. boxes and before being placed in the kettle was sorted

by dumping the scrap into another box, the foreman watching out for foreign matter, and breaking up any large lumps. Twelve hundred pounds of ammonium nitrate was then put into the kettle with scoops, being added slowly, so as to not clog the paddles.

About one-and-a-half to two hours was the time generally required to bring the mixture to the proper point of temperature, between 90° and 95° Centigrade. This temperature was obtained with a steam pressure in the jacket of the kettle from five to ten pounds per square inch.

When thoroughly mixed, the amatol was run off from the base of the kettle through a cock into a steam jacketed pipe running down to the pouring room, where it was drawn off into two-gallon pouring pails and then poured by hand directly into the shell. The first pour of amatol was made to within four inches of the top of the shell, and it was then allowed to cool from 35 to 40 minutes, after which time a wooden probe was used to break down the crust and eliminate all cavities. A second pouring of amatol was then made to fill up the shrinkage cavities. To complete the shell charge and make a suitable watertight seal, a surround of pure T.N.T. was then poured into the shell. After cooling for half an hour or more, the booster former was removed and the shell carried by a belt conveyor to the booster and adapter room, where any amatol or dirt on the outside of the shell was scraped off with putty knives or wire brushes.

Boosters and adapters would have been inserted in this room, but up to the time of the explosion this had not been done, as these components had not been received in sufficient quantities to permit this operation.

The shell were then thoroughly cleaned, shellaced, marked and after gauging loaded into a freight car.

Adjacent to the main loading building was the shell hospital, in which shell temporarily rejected for undue cavitation, badly made or cracked T.N.T. surround, etc., were rectified. On the night of the explosion, no work was being done in this building.

In general, the operating conditions in the 6.1 unit appeared to have been very good, and it was the last one in which trouble would have been expected.

However, the safety precautions employed to guard against the danger of foreign substances in the kettles were not sufficiently effective. The T.N.T. could have been screened without great difficulty, and without materially slowing up the operation of loading the kettles. Testimony afterwards showed that at times nails, wood, paper, and other foreign substances got into the kettles. An even greater risk arose from the use of amatol scrap or waste. Not over 10% of clean scrap could be used in each loading of a kettle. The only required sorting of this scrap was such examination as could be made by dumping the scrap from one box into another,

and breaking up any large lumps. Booster formers, nails and other foreign matter was found in this scrap, and at times dirty scrap was used.

On October 4th, 1918, there were about 54 persons, exclusive of inspectors, employed on the 4 to 12 P. M. shift in the 6.1 unit. All the men had been working there for a period of at least a week or ten days. Neither the night assistant superintendent nor the assistant division chief inspector were at the unit on the night of the explosion on account of illness and the guards had also been reduced through illness from six to four men.

There was some question as to whether any of the kettles were loaded between 4 P. M. and the time of the explosion. Orders had been given that they should not be filled, and the inspector who left at 4 P. M. stated that they were all filled when he left, with the exception of the one from which they were drawing. On the other hand, the steam fitter of the unit, who was in the kettle room at 5.45 P. M. stated positively that he saw a colored man dumping a box of T.N.T. into a kettle.

At some time between 7.30 and 7.45 P. M., a heavy explosion occurred in the 6.1 unit. There was no previous warning, indicating that it was instantaneous and not preceded by fire. An examination of the survivors of the unit showed that not only was there no warning, but that the majority of them saw nothing and knew nothing as to what had occurred until they came to in the wreckage, and managed to escape. One of the guards stated that he saw a flash come from the cleaning end of the loading building, followed instantaneously by explosion. He saw no flare either from the T.N.T. service magazine or from the shell hospital.

Officers and employees of the Company who arrived on the scene shortly after the explosion found that the central part, or kettle room, and the north end of the loading room, were completely wrecked and burning fiercely. The testimony established conclusively that the initial explosion occurred in the loading section of the building, either in the kettle room or in the pouring room. The theory worthy of most consideration was that the detonation occurred in an amatol mixing kettle, containing 2600 pounds of high explosive.

Several explosions immediately followed. Judging from a crater 5 feet deep and 25 feet in diameter, a second amatol kettle was thrown to the first floor by the first explosion, and detonated from the burning wreckage exactly in the center of the building.

When the firemen arrived on the scene a few minutes after the first explosion, shell in the shipping and painting room were exploding, and boosters were popping. Shortly after 8 o'clock there was another heavy explosion, the detonation of between 200 and 475 shell stored in the shell hospital. The roof of the shell hospital had been previously demolished, and was on fire. This explosion made a crater 5 feet deep and 35 feet in diameter.

The first or second explosion set fire to the T.N.T. service magazine which burned to the ground, and also a car of T.N.T. on the side track just outside the service magazine was destroyed by fire.

During this time, or from half to three-quarters of an hour, the firemen had been able to keep three streams of water on the burning unit. At about 8.25 P. M. a third heavy explosion took place, which was probably the explosion of 800 loaded shell, which were in a car by the shipping room, and which made a crater 4 feet deep, 35 feet long, and 25 feet wide. This explosion caused the firemen and all others in the vicinity of the unit to seek temporary refuge from the bursting shell. About 15 feet of the 10 inch water main was blown out by this explosion, and shortly after it was discovered that the water pressure was lost.

Other explosions, probably consisting of small groups of shell in the painting and finishing room, formed craters on the site of the 6.1 unit.

The exploding of boosters and individual shell or small batches of shell was continuous from 7.40 P. M. to some time after what is called the third explosion, about 8.25 P. M. Several persons, including two firemen, were injured by shell fragments during this period.

After the third explosion, shell began to fly so fast that it was impossible for anyone to remain within the vicinity of the 6.1 unit, and all were forced to seek temporary refuge. All serious effort to check the spread of the fire and to protect the rest of the plant was abandoned, after breaking of the water line.

Up until midnight, no serious destruction was caused outside of the 6.1 unit. An electrical warehouse and another small warehouse in which nails were kept had been set on fire either by falling shell or embers and had burned to the ground. Fire started in the 6.2 unit about 9 o'clock and destroyed the service magazine; but this fire died down and there seemed to be a reasonable expectation that it would not be communicated to the unit proper.

At or about 1 A. M., the fire in the 6.2 unit burst out again with great violence, and at about 2 A. M. intense clouds of black smoke and brilliant flames issued from the unit, followed in a few minutes by a terrific detonation, probably due to the mass detonation of all the shell stored in the unit. This explosion formed a crater 5 feet deep, 60 feet wide, and 70 feet long. Over this spot about 500 loaded 155 m/m and 8 inch shell had been stored.

It is probable that the detonation of these shell in the 6.2 unit threw hot shell on to the yard tracks and detonated a large number of carloads of loaded shell which were standing on a track near the unit. These carloads of shell exploded thereafter at reasonably regular intervals, and caused the detonation of three carloads of T.N.T. on the track between the 6.3 unit and

the railroad yard. The detonation of these loaded cars completed the destruction of the water mains.

The detonation of the cars of shell may have projected hot shell into some of the storage buildings, and caused the detonation of other shell stored therein. The 6.3 and 9.1 units must have been practically demolished by the explosion of the three cars of T.N.T. on the main railroad track, and undoubtedly caught fire soon thereafter. Any attempt to state the order in which various buildings and units thereafter caught on fire or their contents detonated would be too conjectural to serve any real purpose.

A large crater was caused by the detonation of the contents of the 6.5 unit service magazine, containing 22,000 pounds of T.N.T. It made a hole 15 feet deep and 50 feet in diameter.

The detonation of 38,000 pounds of T.N.T. in the 9.1 unit made a crater 6 feet deep and 20 feet in diameter.

Based on past experience, ammonium nitrate had not been in itself considered an explosive. The explosions at this plant proved, however, that when sufficient carbonaceous material is present with ammonium nitrate an explosive results which can be readily detonated. The probable explanation of these detonations of ammonium nitrate is that various ammonium nitrate storages first caught fire; that the ammonium nitrate was melted down by the heat of the fire, and that detonation resulted from the projection into this molten mass of one or more shell which detonated upon impact.

It seems probable that a heavy explosion which occurred about 4 A. M. was either the ammonium nitrate storage in the 9.1 unit, containing 1,000,000 pounds, and which made a crater 30 feet deep, 140 feet wide, and 150 feet long; or the ammonium nitrate storage in the 6.4 plant, which made a crater 12 feet deep, 125 feet wide, and 200 feet long.

There were six craters made by the explosion of ammonium nitrate, but the size of the craters did not correspond with the quantities of ammonium nitrate stored in the magazines, which would indicate that in some cases only a portion of the ammonium nitrate detonated, the extent of the detonation presumably depending on the amount of carbonaceous material in the magazines, and the extent to which the flames had reduced the ammonium nitrate to a molten state before the projection of a shell into it.

The 7.1 unit was probably fired from loaded shell projected into it from the 6.3 unit, and the same cause started the fire which destroyed the 7.2 unit. The detonation of loaded shell in the 1.10 building was probably caused by a detonation of a mass of nitrate of ammonia stored in the 6.6. unit, from which fire was thrown to the 1.10 buildings.

Two smokeless powder warehouses were probably set on fire by the projection into them of shell which detonated on impact. The third smoke-

less powder warehouse was not affected by the fires in the other two, and remained intact.

Another interesting point in connection with the explosion was that large quantities of loaded shell, both in cars and in storages, detonated en masse, contrary to previous experience. The simultaneous detonation of more than 66,000-155 m/m shells, made a crater 25 feet deep, 100 feet wide, and 600 feet long. Mass detonations must also have caused the large craters under eight cars containing 155 m/m shell.

All of the operating units within the plant were demolished, except the 4.1 unit which, though badly damaged by concussion, did not burn, and one or two buildings were still standing in the 7.2 unit. While the storage buildings themselves were more or less structurally wrecked, only five out of the 41 were completely destroyed. None of the T.N.T. storage magazines located around the hill at the southwest corner of the plant burned or detonated.

On October 4th, 1918, there was on the Morgan Plant in magazines, storage, and operating units, and on freight cars, over 30,000,000 pounds of high explosives, of which nearly 12,000,000 pounds were destroyed by fire or explosion. Large quantities of explosives were on cars in the Ernston Yard and tracks within the plant, the lack of storage facilities and tracks making it impossible to unload them.

There were also 1,013,458 loaded shell at the plant on the date of the explosion, in magazines, storage and operating units and on freight cars on tracks throughout the plant, and of this quantity 308,239 detonated or were destroyed.

Completed rounds were also shipped to the plant in excess of its storage capacity.

The urgent necessity of shipping shell to France as rapidly as possible, the lack of storage facilities at other points, the lack of steel rails and corrugated iron needed for constructing magazines, the shortage of lighters after September 26th in which to ship the completed rounds, and the delay in receiving boosters for the loaded shell, combined to cause the congested storage conditions at the Morgan Plant.

In the confusion resulting from the explosion, and with all the employment records destroyed, it was difficult at first to determine the number of killed. After several days a report was issued, fixing the number of dead at 64, including 12 Government inspectors. The number of injured was variously reported, ranging from 50 to 100.

Of the 700 buildings on the plant, 325 were destroyed, including all cottages and residences. The 40 buildings of the labor camp were intact. The power house, wharves, traffic system, storage warehouses and maga-

zines were not damaged to any extent, the main storage area being at a proper distance.

No one was killed outside of the plant itself. In the neighboring towns, the fear that the T.N.T. in storage magazines would explode caused the inhabitants to leave their houses in panic during the night, and much suffering was caused by exposure to the weather. As late as 12 o'clock noon on the following day, the inhabitants of nearby towns were advised to leave their houses, such was the dread of further explosions at the plant.

Some serious structural damage was done in South Amboy and Keyport. In Perth Amboy, and in some other towns, there was considerable vacuum damage caused by the pulling out of window frames and doors, the lifting of roofs, etc., but there was little or no structural damage beyond a mile and a half from the plant.

In most cases, shells were thrown a comparatively short distance, not exceeding a mile, with the exception of one shell which was projected about a mile and a quarter.

Investigation was made as to the extent of the damage done, but from the standpoint of a study of damage at definite distances which would be based on a given quantity of explosives, there is little of real value to be learned from the Morgan explosion.

It would be impossible to state with definiteness and accuracy the cause of the initial explosion. It was well established, however, that it occurred in the kettle room of the 6.1 unit, and was the detonation of the contents of a kettle. The probable causes of the explosion, after careful consideration of the opinions of explosives experts, were reduced to the following:

The sensitization of the mixture in the kettle, either by impurities in the T.N.T. or nitrate of ammonia, or by the introduction into the mixture of some foreign matter, such as broken glass, dirt or other grit, nails, or pieces of iron from the amatol scrap or T.N.T.

Friction might have resulted from the action of the paddle against foreign metal substances, friction might have resulted in fire, and fire in detonation.

A spark or a small detonation, resulting in the detonation of the entire contents of the kettle might have been caused by the action of the mushroom valve at the base of the kettle; or from the improper probing of a frozen valve with a bar of iron, or other metal.

A belt might have come off the kettle because of friction in the kettle itself resulting from a broken paddle, and undue force might have been used to keep the belt on, causing the contents of the kettle to fire and detonate.

All these probable causes find some support not only in theory but in conditions that had existed in the 6.1 unit.

In addition to these theories of accidental explosion, it was thought

that an enemy agent might have detonated the kettle by the introduction therein of a fulminate of mercury cap, or other detonating substance, either personally throwing the same into the kettle, or by placing it in the amatol scrap or T.N.T., whence it might have passed unnoticed into the kettle.

The Morgan Plant was the largest shell loading plant in the world, and an alien enemy wishing to cut off the supply of large explosive shell from the Allies would naturally have chosen this plant for his operations.

The date of the explosion was the most advantageous time to have chosen for such a purpose, on account of the accumulation of explosives on the plant, and to anyone familiar with the operations of the plant, the 6.1 unit was the best one to choose on the night of October 4th.

NIXON PLANT, NEW BRUNSWICK, NEW JERSEY

On Saturday morning, March 1st, 1924, between 11 A. M. and 12 noon, there was an explosion in a building occupied by the Ammonite Company on the Nixon Plant near New Brunswick, New Jersey. The Ammonite Company was engaged in the recovery of ammonium nitrate in solution.

A Salvage Company held a contract with the government to salvage shells containing amatol, a combination of T.N.T. and ammonium nitrate. They retained the T.N.T., and the ammonium nitrate in solution obtained from the salvage operation was placed in tank cars and transported by rail about half a mile to the Ammonite Company building.

At the time of the explosion, the amatol recovery operations carried on by the Salvage Company had been completed for about two months, cars and the recovered nitrate of ammonia was being held in broad gauge tank until such time as the Ammonite Company could finish its work, which it expected to do in about two weeks.

The building occupied by the Ammonite Company was constructed of hollow tile, and was about 100 feet long and 50 feet wide. There was an office and a storeroom at one end of this building, a boiler room at the other end, and the center section was used for the recovery process.

The Ammonite Company filtered the solution obtained in tank cars through a filterpress, and then cleaned it further by agitating it with Darco, a special grade of decolorizing carbon. From the treatment tank, the material went through settling tanks and finally into evaporators or grainers, in which the solution under vacuum was reduced to a dry, granular state. Ordinarily, the solution would still contain from 1/10 to 2/10 of a percent T.N.T. when received from the salvage company, but a larger amount would be suspended in the solution if the separation of the T.N.T. from the ammonium nitrate had not been carried out with proper care.

About 6,000 gallons of the liquid, or 60,000 pounds were evaporated daily, and if the solution contained 2/10 of a percent of T.N.T., there would be 120 pounds of T.N.T. to be disposed of daily. As the contents of the solution had been according to one witness as high as 2% in the last shipments, 1200 pounds of T.N.T. would have to have been disposed of daily. If this amount, or anything near it, really was washed down the sewer, doubtless the neighborhood was saturated with T.N.T., which probably was tracked all over the factory, and which on drying must have settled as dust in many places.

The superintendent expected one of the grainers to be finished by noon, and therefore let his men go for lunch at 11 o'clock. The explosion occurred between 11 and 12 o'clock. By this time the product in the grainer must have been dry and quite hot.

From the appearance of the crater, the explosion most probably originated in this evaporating or graining operation. One evaporating pot was found on the site of the explosion, cracked in two parts, while a second evaporating pot or grainer had been broken to pieces, and parts of it blown 450 feet away. A stove tank which was situated nearby was evidently full of liquid at the time of the explosion, and some of the staves were still in an upright position, which would seem to indicate that the explosion did not occur there, but originated in the graining kettle.

The man in charge of the operation was instantly killed, as well as a girl and two men in the office. One man in the boiler room was killed, and four others seriously injured. A woman and three children were killed when their house, about 300 feet away, was blown to pieces. Five or six carpenters working on the roof of a building about 1000 feet away were killed when the building collapsed. Two other men were missing, making a total of 17 people killed and at least 15 injured in the explosion.

It will probably be impossible ever to determine the amount of explosives involved, but from the appearance of the crater and the damage resulting from the explosion, it was evident that there was a considerable quantity, since it would require 50,000 or more pounds of dynamite to cause the damage that resulted from this explosion.

The amount of ammonium nitrate on the plant on the day of the explosion was estimated at 10,000 pounds, stored in barrels between the office and the operating room. It was entirely consumed by fire, and the position of the barrels was hardly disturbed at all by the explosion, the barrels burning and the hoops dropping down in position of the barrel.

There were two tank cars, evidently in front of the building, which probably contained the ammonium nitrate in solution. One tank had been ripped off the truck and a side plate dented. There was still a crystalline residue in the bottom of this tank. The second tank car had been quite

badly damaged. The dome was dented in, and the section between the dome and the end of the tank had evidently been burst open and flattened out, while the end of the tank had been carried about 400 feet over some scrub timber and into the Raritan Arsenal grounds. The portion of the tank remaining near the building contained a crystalline residue, and the section which was carried over into the arsenal grounds also contained some of this same material.

There was a tank car in front of the building that was partly loaded with the finished material. The car was ripped to pieces by the explosion, but the flooring was still in place and some of the material remained in the car.

The force of the explosion was in the direction of Raritan Arsenal, and the dwelling in which the woman and children were killed was in a direct line with it. In this same line there were a number of Raritan Arsenal magazines, standard ammunition warehouses 50 feet by 150 feet in size. The walls were of 8-inch hollow tile with brick pilasters directly under each roof truss, or about 20 feet centers. The walls were about 12 feet up to the plate line. The hollow tile construction did not stand up as well as might have been expected under the shock of the explosion. The brick pilasters showed considerably more resisting power than the hollow tile walls. The roofs of these buildings were gypsum slabs laid on purlins and covered with prepared paper roofing. These light slabs offered little resistance to the explosion.

One of these magazines was completely ripped to pieces and flat on the ground, with the exception of one end wall, of which about 12 feet was still standing. The magazines on each side of this one were about two-thirds demolished, leaving a portion of the roof and one end of each building. In the next line of magazines beyond these, the damage consisted principally of roofing ripped off, roof supports broken, and corners of the building damaged. Quite a number of other magazines suffered damage to the end walls, principally at the corners.

The Nixon pyralin plant, constructed for the most part of glazed hollow tile, was badly damaged. The walls facing the explosion were pulled out, and the roofing collapsed.

All the damage beyond 300 feet seemed to be due to the vacuum; the walls of the buildings were all drawn toward the point of the explosion, as was the case in the magazines at Raritan Arsenal.

A number of men working in the most seriously damaged magazine at the arsenal were injured and sent to the hospital. They would probably have been killed if the cases of ammunition in the magazine had not protected them from the falling roof timbers.

As the quantity of explosive involved was not known, the explosion

at the Nixon Plant is of no value in measuring damage done at different distances.

The plume from the explosion, according to witnesses, was of a greyish color rather than black, which indicated that the explosive was not entirely T.N.T.

NORTH CHARLESTON, SOUTH CAROLINA

There was an explosion in a black powder magazine at North Charleston, S. C., at 11.45 A. M., on April 13th, 1922.

A Salvage Company held a contract with the government to salvage obsolete ammunition, and the salvaging operations were conducted on a strip of land belonging to the government, just outside of the fenced-in reservation of the ordnance depot at North Charleston, about seven miles from the city of Charleston. The entire salvaging plant occupied a space about 1,000 feet long and 150 feet wide.

The magazine in which the explosion occurred was about 35 feet from the railroad tracks used by the Ordnance Depot, and about 225 feet from the tracks of the Seaboard Air Line. The magazine had been constructed by filling empty 3-inch projector boxes with sand, and placing them on top of each other, making walls approximately 3 feet thick, and stretching a tarpaulin across for a roof. The magazine was about 15 feet by 20 feet, and 10 feet high.

The salvaging operation on the plant consisted of unloading steel shrapnel shell. After the black powder bursting charge was removed, it was placed in a wooden box, and later repacked into 100 pound smokeless powder zinc-lined wooden boxes. Covers were placed over these boxes, and they were carried by wheelbarrow down to the black powder magazine, where the powder was placed in standard 25-pound steel kegs, to be stored until it was ready to ship.

At the time of the explosion there was between 20,000 and 25,000 pounds of powder in the magazine, in charge of a white man with two colored assistants.

On April 13th, the Salvage Company was preparing to make a shipment of a carload of black powder. For some reason, some of the steel kegs had not had the required felt washer put under the indented circular stop which fits over the filling hole. The foreman was engaged in reopening these kegs, to put in the felt washers under the metal stop, for which purpose he was using a brass chisel which had been furnished him. At about 11.30 A. M. he left the magazine and went to the Quartermaster Locomotive Engine House about 300 feet distant, which engine house had been rented by the Salvage Company for use as a machine shop. Here he asked for and

secured a cold chisel, and returned to the magazine. The explosion occurred at 11.45 A. M.

The foreman was instantly killed. The explosion tore a cone-shaped crater in the earth where the magazine had stood about 50 feet in diameter and 18 feet deep. The Ordnance Department railroad track about 35 feet away was completely destroyed, and the rails were bent almost double.

In the car storage yard, about 200 feet away, 95 box cars were damaged. Windows were blown in and doors torn off their hinges in the government reservation houses half a mile away, and had it not been for the railroad equipment between the point of explosion and the reservation, which protected the houses in which many women and children were living, the loss of life and property would have been heavy.

OAKDALE, CALIFORNIA

At 9 o'clock on the evening of March 8th, 1912, there was an explosion in a powder magazine near Oakdale, California.

The magazine, which belonged to a construction company, stood in a plowed field outside of the city limits. It was constructed of 3 inch lumber covered with sheet iron, and was fire and bullet proof. It was not barricaded, and the surrounding country was flat, affording no protection.

The magazine contained 800 kegs of black blasting powder amounting to 20,000 pounds, and 400 cases of 40% dynamite, each containing 50 pounds.

Just before nine o'clock, a neighbor in a house about a quarter of a mile away saw the light of a fire, and soon after heard the first explosion, followed by the second.

The east side of the building was blown as a whole about 20 feet from the original position. The roof and three other sides were scattered from 40 to 450 feet away. Every can of black powder in the magazine was destroyed, but only one case of dynamite exploded, probably the second explosion that was heard. Forty-six unbroken cases were scattered from 20 to 60 feet from the magazine. Many were badly charred by fire, but the contents were undamaged. About 20 other cases were found broken open, and the sticks of dynamite scattered over the ground. The rest of the dynamite burned.

The fire which caused this explosion was thought to have been of incendiary origin.

The sheet iron covering of the powder magazine was attached to the framework with wood screws. Each sheet was about 4 x 10 feet and $\frac{1}{4}$ inch thick. Many of these sheets of iron were blown 300 feet from the site of the

explosion. One piece was badly twisted. Two or three of these sheets of iron tore through the wire fence along the road, wrecking it, and one piece ploughed into the ground to a distance of five feet. Distorted cans that once contained the black powder were scattered in every direction, in some cases as far as 750 feet from the building.

Very little damage was done by this explosion. No one was killed, and there were few buildings in the neighborhood on which damage could be measured. Glass was broken in a few instances as far as 1000 feet.

OPPAU, GERMANY

There is given below a report of an accident involving a chemical which, though not believed to be an explosive, nevertheless behaved in such a manner as to be of interest, and it is therefore included.

On the morning of September 29th, 1921, at about 7.30 A. M., the synthetic ammonia factory at Oppau, Germany, was the scene of one of the most disastrous explosions which has ever occurred in the chemical industry.

The plant occupied an area of about 2000 acres. The works were constructed in 1913 and were operated by the Badische Anilin und Sodafabrik, who began producing in 1918 a new fertilizer derived from ammonium nitrate, obtained either by double decomposition of ammonium nitrate with chlorides, or by combination with an inert salt such as ammonium sulphate. These two products were named "Kali-ammon-salpeter" and "Ammonsulfat-salpeter." It was established that it was the explosion of 4,500 tons of the latter which caused the disaster at Oppau.

Exhaustive experiments had been made by the company to determine whether these substances were capable of being stored and shipped in large quantities, and they were perfectly satisfied with the results. Their experiments established that a mixture of 60 parts of ammonium nitrate and 40 parts of potassium (or sodium) chloride entered into a chemical reaction, producing a mixture of potassium nitrate and ammonium chloride. A mixture of equal weights of ammonium nitrate and sulphate produced a double salt, and this substance had been sold with a slight excess of the sulphate. Numerous tests of the explosive powers of this mixture, with nitrate content up to 60%, were made by the Trauzl method, but with negative results; in fact, when endeavoring to detonate the salt with fulminate of mercury, the explosion of the latter was less violent with the salt than it would be without it. The Badische Company were so confident of the safety of their new product that it was their custom to break up large masses of it by the aid of explosives.

Unfortunately, it will never be possible to discover what happened at

Oppau immediately before the explosion, since none of those present in the buildings concerned survived.

An eye witness stated that he saw a high column of flame shoot up, followed almost immediately by a detonation which knocked him down; there was a short interval, estimated at two or three seconds, and then a second much more violent report and a great fog of dust and fumes spread over the works and village. Ammonia gas was also reported to have escaped in large quantities, indicating injury to the synthetic ammonia apparatus. The greater violence of the second detonation was also confirmed by the seismograph record. All church clocks in the neighborhood stopped at 7.33 A. M.

The general material effect of the explosion was most serious. The buildings where the explosion occurred were completely demolished. Large fragments of machinery were blown about, reaching as far as the village. In the village itself, which had a population of 5000, about 75% of the houses were in ruins or uninhabitable. A crater 400 feet in diameter and over 90 feet deep was formed on the site of the explosion.

Important damage was done at Mannheim, four miles away, where 3 persons were killed and 17 injured, and the effect of the explosion was also felt at Karlsruhe and Heidelberg. The concussion was felt as far as Munich, 175 miles distant.

The casualty roll at Oppau was greivous. Although general work had not begun at the plant at that time in the morning, there were 850 people at the works. The death roll was variously stated; the first reports gave 700 killed and over 1500 injured, the latter figure including many casualties in the village. Later reports gave the number of killed as 1000 to 1100, including casualties in the village, and a newspaper report gave over 400 killed and several hundred injured, which was probably a minimum estimate.

The cause of the explosion was not known. Evidence submitted indicated that work at the factory had recently been so speeded up, that the material had arrived at the silos in a warm state, and that the workmen asked to have the silos flooded; also that employees had been discharged for refusing to work in the storehouse, owing to the fumes given off.

Careful study and investigation of all details of practices in vogue at the factory failed to attach blame for the explosion to the methods of operation. After an investigation, it was announced that the explosion was one of those plant accidents, the causes of which could not be definitely determined, even with the complete assistance of science and technic.

Although the investigation brought out some interesting circumstances, nothing of value could be learned from it.

To avoid the repetition of such an accident, the breaking down of stocks of ammonium nitrate, ammonium nitrate sulphate and similar com-

pounds by blasting was ordered discontinued, and in future these materials were to be broken up by mechanical means.

PANAMA CITY, PANAMA

At 3.15 A. M. on the morning of May 5th, 1914, a severe explosion occurred in El Polverin, the municipal powder magazine near Panama City, Panama.

The magazine was built of stone, surrounded by a stone wall about a foot and a half thick. It was situated on the Corozal road near the Curundu River, about $2\frac{1}{2}$ miles from Panama.

At the time of the explosion it contained about 4,000 pounds of dynamite and 30,000 pounds of black powder, making a total of 34,000 pounds of explosives, some of which was in a damaged condition. There were also some dynamite detonators stored in a zinc-covered addition built against the southwest wall of the magazine. There was no watchman on guard, and it was never known how the fire started which caused the explosion. Smoke was first seen near the place where the dynamite detonators were stored, and firemen were on the spot when the explosion occurred at 3.15 A. M.

Six firemen were killed near the wall, and three other people at distances up to 900 feet. The watchman at the Bull Ring and his wife left their children in the basement and climbed to the top of the building to see the fire more plainly. They were instantly killed, but the children were unhurt. Ten people were severely injured by flying missiles and glass, and twelve others suffered slight injuries.

At a dairy, about 750 feet from the explosion, the house was torn down, one of the galleries broken, and some animals wounded. The head of a calf was struck off, by a large stone, and another stone broke a cow's leg.

At the margarine factory, 825 feet away, machinery was injured and the top floor wrecked.

At the Bull Ring, "Vista Alegre" beams were broken, and the north side of the building splintered, but not damaged past repair.

At the Cantina "Las Delicias", 1000 feet away, panels and shelves were destroyed, and the locks of doors taken off.

At the soap and candle factory, 1500 feet away, the store on the north side was wrecked.

The Santa Isabel Hospital, 1500 feet away, had roofs and ceilings broken, walls tumbled down, and windows broken.

Fragments from the magazine walls and the barricade were responsible for much damage, and were found as far away as 1500 feet, while small missiles and debris were thrown 6000 feet.

In the city of Panama, $2\frac{1}{2}$ miles away, iron doors were damaged, and many dwellings and business houses suffered broken windows, among them the National Theatre and the Variedades.

PLEASANT PRAIRIE, WISCONSIN

This explosion, involving one of the largest quantities of explosives in the history of the world's explosions, occurred on March 9th, 1911, at the Black Powder Works located near the small town of Pleasant Prairie, Wisconsin.

The Works were situated on a practically level stretch of country on a section of 712 acres, over which were scattered the various factory buildings. With the exception of the Power House and a storehouse or two, the buildings were frame construction, in most instances covered with corrugated iron. There was no protection afforded these buildings, either artificial or natural, other than a few trees here and there.

On the evening of March 9th, 1911, the plant was not in full operation, there being only fifteen men on duty. Nine of these men were engaged in unloading Nitrate of Soda from railroad cars to the storehouse, and the others were a night crew consisting of a night watchman, engineer and fireman in the Power House, two men at Wheel Mills and a man in the Glaze Mill.

The Glaze Mill was started up a few minutes after seven o'clock and the explosion took place at 8.16 P. M.

The first explosion occurred in the Glaze Mill. This was followed in three or four seconds by explosion in the No. 2 Black Powder Magazine, which was immediately followed by one in the No. 1 Black Powder Magazine. An interval of three or four minutes elapsed when powder in the Sporting Powder Magazine exploded, instantly followed by an explosion in the Dynamite Magazine. There was also an explosion in Press No. 1 but this was not noticed midst the greater explosions.

The following distances maintained between the buildings in which the explosions occurred:

Glaze Mill	to No. 2 B. P. Magazine	1150 feet (in clear)
" "	" No. 1 B. P. "	1290 " "
No. 2 B. P. Magazine	" No. 1 B. P. "	620 " "
No. 1 B. P. Magazine	" Sporting Magazine	360. " "
Sporting Magazine	" Dynamite Magazine	530 " "
Glaze Mill	" Press Mill No. 1	930 " "

Just what caused the initial explosion in the Glaze Mill was not determined, but beyond a doubt the explosions which followed in the No. 2 and No. 1 Black Powder Magazines, and probably the explosion in Press

Mill No. 1, were due to missiles from the Glaze, in which there were 8 steel barrels, since missiles from this mill were spread over the entire plant property. The heads of the Glaze barrels were evidently thrown like projectiles from a cannon in directions parallel with the length of the barrels. The No. 2 and No. 1 Black Powder Magazines were so located as to be within range for missiles of this nature, which heated as they were to a high point, caused the explosions upon penetrating the magazines.

The interval of time between explosions in the two Black Powder Magazines and the Sporting Powder Magazine gave reason to believe that the cause here could not be laid to missiles from the Glaze Mill, but was probably due to being struck while in a damaged condition by flying kegs of powder from the large magazines, many of which exploded in the air and upon striking the ground even as far distant as 3000 feet from the magazines. The explosion in the Dynamite Magazine was due to either a similar cause or to a missile from the Sporting Powder Magazine.

The various buildings in which explosions occurred contained the following quantities of explosives:

Glaze Mill	25,000 pounds
No. 2 Black Powder Magazine (47,000 kegs)	1,175,000 "
No. 1 " " (40,432 kegs)	1,010,000 "
Sporting " (1,200 kegs)	30,000 "
Dynamite "	71,650 "
Press mill No. 1 (small quantity)	
Total	2,311,650 pounds

The explosion in the Glazing Mill completely demolished the building and machinery. Pieces of concrete scattered around the site and the line shafting with gears were all that remained.

At the location of the large Black Powder Magazines the earth had been excavated by the explosions to a depth of about 30 feet, almost the entire length of the magazines. The earth had been thrown up in the form of a lip 12 or 15 feet above the natural level of the ground and spread in all directions for distances ranging from 600 to 1000 feet. Near the craters, the hard-pan thrown out was in huge lumps. The foundation wall which supported the center of floor of the No. 2 Black Powder Magazine was found at the bottom of the crater to some extent intact.

In the location of the Sporting Powder Magazine, the excavation of small area and only a few feet deep.

At the site of the Dynamite Magazine the excavation made by the explosion was about 30 ft. in diameter and 12 to 15 ft. deep.

The 27 principal buildings of the powder factory were all within a radius of half a mile from the center of the explosions, and all suffered

serious structural damage, 8 of them being destroyed by fires following the explosions.

On the plant property there were also 14 buildings consisting of employees' dwellings, barns, etc., distant from the different explosions 1650 feet to 2900 feet. All of these suffered serious structural damage.

Beyond the boundaries of the plant property and located within half a mile, there were two dwellings and 12 farm buildings, distant respectively from the No. 2 Black Powder Magazine 2100 feet and 2350 feet. All of these buildings suffered serious structural damage, some of them being quite badly shattered.

Beyond the $\frac{1}{2}$ mile radius and within the $\frac{3}{4}$ mile radius there were 6 dwellings and 11 miscellaneous farm buildings, practically all of which suffered serious structural damage, two barns within this zone being quite badly shattered. The one brick residence, distant 3750 feet, was quite badly damaged, in fact more so than neighboring frame dwellings.

Situated from $\frac{3}{4}$ to 1 mile of the explosion, there were 31 dwellings, 40 farm outbuildings, and 11 miscellaneous buildings.

A group of buildings, consisting of a dwelling, cottage and 14 farm buildings coming within this zone, was exposed to the full force of the explosions, no protection whatever existing, and hardly a building escaped serious structural damage. The substantially constructed dwelling in this group, situated rather closer to the explosions than the other buildings, received a good share of the damage.

Within this same zone were the buildings of the small town of Pleasant Prairie. In this group of buildings there were 10 dwellings with outbuildings, in all about 25 structures. The most seriously damaged building was a dwelling, which, owing to the racking and twisting it received, practically required rebuilding.

Generally speaking, the majority of the buildings within $\frac{3}{4}$ to 1 mile zone received more or less serious structural damage.

From 1 to $1\frac{1}{2}$ miles there were about 25 to 30 dwellings, and from 50 to 60 farm buildings.

A farm, distant 6000 feet to the northeast of the explosion, suffered the greatest amount of damage. The farm buildings had damages of a serious structural nature. A large barn, the closest of this group of buildings to the explosion, was badly shattered.

Another farm, also distant 6000 feet, consisted of a group of well constructed buildings. Three dwellings received only minor damages, but a number of the farm buildings were seriously damaged. A concrete warehouse received damages which could well be classed a serious structural damage.

Situated in the zone $1\frac{1}{2}$ miles to 2 miles from the explosion there were about 25 dwellings and 50 miscellaneous farm and outbuildings.

To the northeast, a farm distant about 10,000 feet, had one building structurally damaged. This building, however, was practically a connecting shed between two barns of light construction, and therefore not a fair measure of damage.

To the east, distant about 9,000 feet, a dwelling had 5 floor joists broken, and the barn sufficiently damaged as to verge on the serious structural damage class.

Buildings of a farm, distant about 9,000 feet to the southeast, with an open level country between it and the point of the explosions, received considerable damage of a structural nature.

On a farm to the southeast, and distant about 10,600 feet, a number of buildings were sufficiently damaged to come within class of serious structural damage. These buildings represented an isolated instance of serious structural damage.

Beyond 2 miles, instances of structural damage were rare. On a farm to the east, 13,800 feet, a two-story brick dwelling had rafters broken and the roof slightly lifted, and there was also a farm building which had a number of rafters split on one side of the roof.

On a farm to the east, and distant 14,500 feet, there were two or three farm buildings damaged, one of which had quite a number of rafters broken. This, however, was an old building of light construction and not a fair measure of damage.

Glass was broken over an enormous area. To the north, however, at two or three miles the limit of this class of damage was reached. In the town of Kenosha, which was situated east of the Powder Works on the shore of Lake Michigan, and about 6 or 8 miles distant, there was a large quantity of glass broken, including large plate glass windows. Further east, and across Lake Michigan, a distance of 86 miles, a church in St. Joseph, Michigan, had windows broken.

To the south the area of broken glass extended as far as Chicago, Illinois, distant about 50 miles, large quantities being broken on Madison Street and Milwaukee Avenue. Milwaukee Avenue, which extended northwest to southeast, had the glass broken on both sides of the street, the explosion wave seeming to have gone from one side of the street to the other.

To the west the limits of broken glass were about 5 miles.

The different classes of damage, with limits of areas in which they occurred, were:

Buildings wrecked up to.....	1800 feet
Serious structural damage to buildings.....	6000 "
" " " " " (one instance).....	2 miles

Structural damage to buildings	2 miles
" " " " (few isolated cases)	3 "
Sash, doors and plaster	50 "
Glass broken	85 "
" " (one instance)	

The following is a list of the killed and injured resulting from the explosion:

	Distance from Explosions
Man in Glaze Mill—Killed	00
Man in Power House—slight injuries to spine	On Plant
Girl in Boarding House had ankle cut by glass	On Plant
Man received cuts on head from flying glass	3500 feet
Man received cuts on hand from flying glass	5000 "
Girl received cuts on arm from flying glass, also slight burn on chin from piece of hot keg metal	6000 "
Man had eyes seriously injured by flying glass	2 miles
Man received cuts on ear from flying glass	2 "
Man had leg broken by falling of barn door	10 "
Man suffered serious nervous shock, the effect of the explosion probably being intensified by excitement of man above having leg broken by barn door	10 "

Missiles from explosion in the Glaze Mill were spread all over the factory property. Pieces of the Glaze Barrel shell, weighing 300 to 500 lbs., were thrown 2000 feet. Other metal parts 2350 feet. A 1½" iron rod 10 feet long was thrown 4100 feet.

Missiles from the Black Powder Magazines, consisting of railroad iron, car wheels, and concrete foundation, were thrown as far as one mile.

Small pieces of powder keg sheet metal, two or three inches in area, were distributed over a large section to the south and east of the factory. These pieces were carried to a distance of 2½ miles by the wind.

At about the time of the explosion the temperature was 51 degrees F. The wind was from the west and between 7 P. M. and 10 P. M. the velocity averaged about 18 miles an hour.

RIO DE JANEIRO HARBOR, BRAZIL

On Friday, February 27th, 1925, at 4.30 P.M., there was an explosion in a warehouse on Caju Island, about four miles across the bay to the east of Rio de Janeiro.

This island was situated just off the mainland near the suburb of Nictheroy, opposite the capital, about 180 feet from Ponto d'Areia to the south and the same distance from the island of Conceicao to the north.

The size of the island was about 900 by 300 feet, of irregular shape, rising in the middle, the only occupied parts being the level ground at the opposite ends. On the western end were coaling wharves, small dry-dock

repairing slips, and warehouses for general merchandise and salt. The eastern end of the island was used for storing explosives, inflammables and ammunition in warehouses under the supervision of the Customs.

On the day of the explosion, the warehouses contained the following stores:

In warehouse A., a tall frame building close to the water, 300,000 gallons of cased gasoline and kerosene were stored. Large numbers of casks of resin were piled to the left of this building, and also in front between the warehouse and the water, as well as some lubricating oil in drums.

In warehouse B, which was a long low wooden shed built close to the water's edge, about 20 feet to the right of warehouse A, was stored about 134,500 pounds of high explosives, as follows:

2280 cases of blasting gelatin.
210 cases of 75% dynamite.
300 cases of 62% ammo-gelignite.

Total—2690 cases, or 248,000 pounds.

Under the same roof but in another compartment detonators and fuzes were stored, and about 1000 tins of lubricating oil.

In warehouse C, about 100 feet to the left of the gasoline warehouse, were supplies of turpentine, chlorate of potash, gunpowder, small arms ammunition, blasting caps and sundries. This warehouse had two brick walls.

In building D, a small shed just behind the gasoline warehouse, were stored small arms ammunition, 25 cases of explosives, sulphuric acid in carboys, and caustic soda in small tins.

About 40 feet from the gasoline warehouse, right on the water was building E, a small brick house, used for reconditioning gasoline and kerosene tins.

Except for this brick building, and the two walls of Building C, mentioned above, all the warehouses were of light frame construction.

On the 26th of February, the day before the explosion, two lighters containing about 7000 cases of gasoline and kerosene were moored about 150 feet from the unloading wharf in front of the warehouses. At about 10 P. M. the night watchman on board one of the lighters, with an indifference to the danger of smoking which seemed to have been usual about Caju Island, dropped a lighted match among the cargo, and fire started immediately. There was no means of putting it out on board, and the efforts of the watchman were ineffective. The local fire brigade from Nictheroy was called but had no floating equipment and could not help. In the meantime the contents of the second lighter were ignited. At midnight the

fire department from Rio de Janeiro arrived by launch, with a small pump functioning badly, which could only throw a useless jet of water over the blazing mass.

There was no breeze, and the fire burned steadily all night. The only adequate steps to take would have been to remove the lighters out into the bay or to beach them out of danger from their position in front of the warehouses. The port captain and the chief of the customs police were approached for help, but they replied that the matter was outside of their province. The firemen would allow no private interference, and a stevedoring firm engaged to remove the lighters was informed that they would be held responsible for any damage resulting from their actions.

At 1 P. M. representatives from the Customs visited the island and left "to consider what steps might be taken." During the afternoon of the 27th, the fire had increased in intensity, and larger numbers of burst and blazing cases were scattered over the water on the rising tide, swinging toward the island, and bringing the lighters nearer shore. Men on shore were engaged in beating off the blazing cases. About 4 P. M. the climax was reached when one of the lighters sank, releasing still more burning cans, which spread out in such a manner that it was useless for the men to try to keep them from contact with the staging and waterside buildings, and everyone, including the firemen, gave up the fight and left the island just in time, about ten minutes before the explosion, which occurred at 4.20 P. M.

It was affirmed by one of the employees that before he left he saw that the light wooden staging extending into the water at the side of the explosives shed was already on fire, and catching the wooden extension of the roof on the low building.

On the site of this shed was left a large crater-like opening, which was filled up by the waters of the bay. There was no explosion in warehouse C, and one of the brick walls was left standing, as it was built flush with the dug-out hillside. It was practically the only trace left of any of the buildings. All the buildings and their contents were destroyed, and nothing was salvaged but a little small arms ammunition from warehouse C, and the casks of resin by the gasoline warehouse.

Fifteen people were killed in the explosion, and it was estimated that about 150 were injured. Twenty people in a rowboat escaping from the island were uninjured, although they were only 300 feet away from the explosion, and mud and debris fell into the boat and in the water all around them. Missiles in the form of pieces of rock, lumber and sheet iron were thrown to distances from 1500 to 3000 feet, falling in the section of the city of Nictheroy known as Ponto d'Areia, the nearest point on the mainland. This section, containing stores and houses of the poorer classes, suffered the most.

On the island itself, the shops of two shipping companies had their roofs blown in, and other warehouses were completely destroyed.

On the next island, 180 feet distant, half a dozen small houses were razed to the ground and several boats on shore had their sides stove in. Damage in Rio de Janeiro was limited to broken glass, to a distance of five miles from the explosion.

SEATTLE HARBOR, WASHINGTON

There was an explosion on a barge in Seattle Harbor, Washington, at 2 A. M., on May 30th, 1915.

A shipment of high explosives, 415 cases, or 22,410 pounds of 90% nitroglycerin blasting gelatin, and 207 cases or 11,178 pounds of 80% nitroglycerin gelatin, a total amount of 33,588 pounds, had been forwarded by the steamship F. S. Loop from San Francisco on May 9th, consigned to a shipping company in Tacoma. It was to be transferred from Seattle to Tacoma by a launch and tug boat company, the shipment marked "FOR EXPORT TO RUSSIA", destination Vladivostock.

When it arrived at Seattle, on the afternoon of May 13th, it was transferred by the launch and tug boat company to barge No. 3, which was towed to and secured to buoy No. 1 on the morning of the 15th, by order of the harbor master.

There were no other explosives aboard the F. S. Loop, nor were there other explosives or inflammables other than the regulation signal lamp aboard the barge. Barge No. 3, capacity 150 tons, was a flat bottom deck scow, with no watchman's quarters or place for fire aboard. Its approximate dimensions were; length, 80 feet, beam 22 feet, depth 5 feet 6 inches; draught with dynamite cargo, one foot. The 33,588 pounds of explosives were loaded toward the rear, piled 4 cases high in the middle, 3 on the edge, and covered with tarpaulin nailed to the deck on all sides. Only U. S. regulation lights, red lanterns, were allowed on board the barge, hung on a pole about 40 feet above the dynamite.

The explosives remained on the barge tied up to the buoy in Seattle Harbor for over two weeks, delayed because the Japanese line raised its freight rates to Vladivostock, and the forwarding agents were holding the shipment pending negotiations for a lower rate.

Elsewhere in the harbor was secured barge No. 6, of about 350 tons capacity, loaded with about 250 tons of Australian slack coal. It was about 90 feet long, 30 feet wide, and its draught with the coal cargo was about 3 feet. On May 28th, the harbor master directed this coal barge to be moved and secured to the buoy alongside the barge loaded with explosives.

Both barges were substantial, built of wood, deck four inches, bottom four inches, sides and ends six inches braced and partitioned longitudinally and transversely. The side planking was bolted together.

The weather from May 13th to May 31st was normal, little rain, and a temperature between 72°F and 55°F. At the time of the explosion there was little wind, sky clear, and the moon shining. The night watchman on the nearest boat in the harbor said afterwards that he had seen the barge a few minutes before the explosion.

The launch and tug company said that they had one of their launches guard the barge loaded with explosives. About 6 P. M. preceding the explosion, their boat took out and placed the regulation U. S. light. The company also claimed that they had taken out a watchman called "Fat", occasionally employed by the company in harbor work. Neither the company nor anyone else knew this "Fat's" identity or correct name, and there was no evidence nor witness that a launch had taken out the watchman at 8 or 9 o'clock, as the company stated. There was also a doubt that the explosives were watched at all times, either by launch or individuals as required by their permit, nor did they have a crew aboard, to comply with the regulations governing explosives in the harbor.

It was never discovered what caused the explosion. The night watchman on the S.S. "Manning" and "Restorer" saw no fire before the explosion occurred. The weather conditions and manner of loading were not such as to cause the cases to rub against each other, to cause exudation or freezing. It was doubtful whether the explosives were properly watched and cared for at all times. Public sentiment favored the theory that the explosion was caused by Teutonic sympathizers.

There was no loss of life, unless the alleged watchman "Fat", nationality, antecedents and correct name unknown, was killed. There was not sufficient substantiated evidence to believe his life was lost.

Had the explosion occurred during business hours, or prior to 11 o'clock P. M. when crowds were on the streets, in buildings, amusement places, etc., flying glass, windows, doors and frames, plastering, etc., would more than likely have injured many, possibly killed some, and caused a general panic in Seattle.

The barge was about 950 feet from the south shore line, 6000 to 10,000 feet from West Seattle, and the following distances from pier lines:

Connecticut Street—2800 feet.

Jackson Street—4600 feet.

Yesler Way—5300 feet.

Stewart Street—6700 feet.

Cedar Street—8150 feet.

To the west the ground rose rapidly from the water line to an elevation of 300 to 400 feet. West Seattle is a residential section with a few cottages and picnic resorts along the shore. The buildings in this section were generally frame.

To the southwest the ground was level from the water front to a distance of 5000 to 7000 feet from the barge, then rose rapidly to an elevation of about 300 feet. The level section was occupied principally by mills, manufacturing plants, railroad yards, warehouses, etc., principally frame buildings. The high land was residential.

To the south and southeast were Duwamish Flats, filled in land used for railroad yards, mills, warehouses, factories, and a few residences, sparsely built up, except on the slope of hills. Buildings were principally frame, with a few brick and steel construction warehouses.

To the east and southeast, between the water front and Seattle Boulevard, there was level ground used for railroad yards, railroad freight houses, warehouses, wholesale section, factories and cheap lodging houses. The buildings were brick, with a few structural iron and wood in this section.

The section east of Seattle Boulevard and King the ground rose rapidly to an elevation of 300 feet. Here there were principally small shops, retail stores, frame dwellings and lodging houses, generally of frame construction.

To the northeast and east, between Railroad and 5th Avenues, King and Cedar Streets, were the principal office buildings, department stores, large stores, hotels, apartments, and a few residences, mostly substantial buildings of brick, concrete, structural iron, with a few frame houses.

East of 5th Avenue and north of Cedar Street was a residential and apartment section with a few stores and shops; a few brick buildings, but principally frame.

The damage to shipping, in addition to the barge itself, which was completely pulverized, was as follows:

Barge No. 6, tied up to the same buoy with the barge on which the explosion occurred, was capsized, bottom sprung, sides warped, one end smashed in, deck broken 12 feet back of end, interior partitions, bracing, and end of side nearest the explosion badly damaged. After the explosion it was picked up and towed toward Tacoma for repairs. The 250 tons of Australian slacked coal went to the bottom. This coal, and the side of barge No. 3 acted as a cushion protecting barge No. 6, otherwise it must have been completely demolished.

Some glass was broken on the S.S. Manning, 1000 feet away, and on the S.S. Restorer, 1600 feet away.

On shore the structural damage was as follows:

An abandoned frame hardwood mill, two stories high, very strong and in good condition, unprotected, had rafters and purlins broken, shed roof

broken in, doors, windows and window frames toward the explosion broken in, and broken out on the opposite side. This mill was 900 feet from the explosion.

About 30 one-story frame shacks, poorly constructed and unprotected, from 1100 to 1200 feet away, were uninjured except for broken glass.

Albers' Mills, docks, elevator and warehouses, (two separate frame buildings) built on pile foundations, very strong, unprotected, about 2560 feet away, had the end of each building pulled out about two feet, and a few purlins cracked.

Piers from Connecticut to Stewart Streets, 75 to 100 feet wide, 300 to 800 feet long, piles and frame construction, had only a small amount of glass broken and office doors pulled open. The apparent reason that so little damage was done was that the main side and end doors of the dock stood open at the time of the explosion.

Warehouses and office buildings up to 6720 feet suffered slight damage, broken glass and sash pulled out.

Southwest, south, southeast and east of the explosion the section known as Duwamish Flats suffered slight damage to warehouses, mills, factories, etc., the majority had some sash and glass broken and pulled out, and many of the larger ones had most of the sash and glass in some direction pulled out.

Plate glass was broken in Everett, 33 miles away, in Bremerton, 14 miles away, and in Rainier, 10 miles away.

In some localities, as much glass was broken parallel to the force of the explosion, i.e., on side streets, as at right angles to the force of the explosion. In some sections plate glass would be broken, several skipped, then several more broken. The effect of the explosion was freakish, for in some cases the marble base supporting a plate glass window would be broken or cracked and the glass intact. Frequently glass on one side of the street would be completely broken, and the other side of the street intact. In some sections, all the broken plate glass in buildings would be on the ground floor, while in others it was broken out on the second and third. Vacant stores and buildings with large unoccupied spaces apparently suffered the most damage.

Two 6 inch iron bolts which had held the side planking together on the barge were found respectively 1400 and 2150 feet distant from the explosion.

SUMMARY			
Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Ware-houses	No protection	End of building pulled out, purlins broken	2560
		Area of structural damage.....	2560 feet
		Missiles thrown.....	2150 feet
		Glass broken, up to.....	33 miles

WILMINGTON, DELAWARE

At 10.25 o'clock on the morning of Wednesday, May 31st, 1854, there was an explosion in the streets of Wilmington, Delaware, when the contents of a powder wagon blew up, involving two other wagon loads of powder.

The three heavy covered wagons were each drawn by five horses, harnessed tandem. They were on their way from the powder mill to the wharf, where the powder was to be stored in a magazine. Each wagon was loaded with kegs holding 25 pounds of powder, the total quantity in the three wagons amounting to 400 kegs or 10,000 pounds.

The train of wagons had turned into 14th Street from Tatnall, and the foremost team was reaching the corner of Market Street when the explosion occurred. The next team was midway between Market and Orange, and the last team was at Orange and 14th. The wagons were about 50 feet apart.

The contents of the wagons exploded one after another, in rapid succession. The three drivers astride of their horses were instantly killed, and the wagons entirely demolished, the scattered fragments when collected scarcely filling a cartbody. The fifteen horses were blown to pieces.

This accident occurred in a residential section a pleasant part of town near Brandywine Creek. Eight houses in the immediate neighborhood were badly damaged, including the Bishop's mansion, a fine brick house standing back 150 feet from 14th Street, and the grounds extended back to the banks of Brandywine Creek. Trees were torn up by the roots, or stripped bare, and the shrubbery was wiped out. The effect of the explosion upon the house was as if it had been burst out from the inside. The greater part of the front wall was thrown down, and the parts that remained standing were rent from top to bottom. The roof was broken upward as if from an inside force, and doors and window frames burst out. The Bishop and his wife were at church, and his two nieces who were at home escaped unhurt, but the colored cook was so badly injured that she died later, and a young Irish nurse-girl was thrown downstairs with a baby in her arms. The child was unhurt, and the nurse escaped with a few bruises.

The large double house adjoining this property was also much damaged. Although it was built in a most substantial manner, the rear wall was bulged out, the roof was raised and thrown out of place, and all the plaster, glass and crockery broken. The stable to this property caught fire and burned. No one was killed in this house.

Another well built residence across the street from the property last described, was injured in much the same way. The stable was wrecked and afterwards burned, and the colored coachman was instantly killed.

A frame house across the street from the Bishop's mansion, and close to the second powder wagon, was badly wrenched and wrecked. The owner

and his wife and child had all their clothing torn off, and were badly bruised and cut, and a journeyman millstone maker in their house was so badly injured that he soon after died from the effects of his wounds. A two year old child buried in the ruins of this house was rescued unhurt, except for a few slight cuts and bruises.

All the buildings in this neighborhood were more or less damaged and a row of seven brick dwellings in the next block parallel with 14th street suffered considerably, and two stables were nearly destroyed.

Thousands of lights of glass were broken in different parts of the city, and plaster was detached from ceilings more than a mile away from the scene. Two windows six squares away with very large panes of glass were dashed out bodily, sash and all, although a hill intervened between them and the scene. In Brandywine Village, across the creek, a great deal of glass was broken, and doors and shutters torn from their hinges.

The exact cause of the explosion was never known, though it was generally believed at the time that some powder from one of the foremost wagons had escaped from a defective keg, and had been ignited by a spark struck by the hoof of one of the hinder horses.

The number of people killed in this explosion amounted to six, and at least five people were injured. One woman in a house on Orange Street not far from the corner of 14th Street had her leg broken.

SUMMARY

Building damaged	Protection	Extent of damage	Feet distant from explosion
Residences	No	Roofs displaced, walls broken	300
Area of structural damage.....			300 feet
Glass broken, up to.....			1 mile
Missiles thrown.....			No record

WILPEN, MINNESOTA

At 10.17 o'clock, on the morning of January 11th, 1912, there was an explosion at the black powder plant at Wilpen, Minnesota.

The glaze mill, in which the explosion happened, was a well constructed, building, barricaded on the three sides next the plant buildings with the standard A-shaped, earth filled barricades, which rose to a height of ten feet above the center line of the glaze barrels.

The weather was extremely cold, the thermometer registering 44° below zero at the time of the explosion, and there was snow on the ground 30 inches deep. The cold had been intense for two weeks. There had been

some inconvenience in running the glaze mill on account of vapor forming thick clouds of steam in the building, and then freezing, but this trouble had cleared up, and there was no difficulty in observing the operation of the machinery and bearings.

The superintendent of the mill and the superintendent of construction had been in the mill just before the explosion and found that everything was running in a satisfactory way. The two operators were about to finish the day's run and clean the two empty barrels. There was 21,000 pounds of powder in the mill.

The superintendent left the mill and had reached the wheel line watch house, about 1800 feet away, when the explosion took place.

The two operators were instantly killed, but no one else was injured.

The cause of the explosion was not known. It could not have been caused from the outside, because the mill was in such a condition from the frost that there was nothing to ignite. The operators were not charging the empty barrels, as they had not been clinkered. The men might have been clinkering the empty barrels.

The destruction of the building and equipment was complete inside the barricade. On the outside of the long barricade, the counter shaft with two friction pulleys were uninjured, and the electrical equipment in the motor house was unhurt. The motor house roof was destroyed, and doors and windows blown out.

Three empty grain powder cars just outside the barricade standing on the tram trestle were somewhat damaged.

The six glaze barrels containing clinkers were torn into fragments of various sizes and scattered over a wide area. Of the empty barrels one lay on the foundations of the fan house between the end and side barricades, the ends blown out and the shells opened flat, but all in one piece. The other empty barrel was found in a similar condition and shape, on the brow of the hill to the northeast about 250 feet away. Two heads of one of these barrels are practically whole, except where the shell is attached on the outer rim, one lying close to the barricade, and the other in the open field about 425 feet to the west.

Of the eight trunions on the east or barricade side of the mill, two were lying inside of the barricade, one was lodged in the upper corner of the south barricade, one full head with trunion was found at the side barricade near the fan house foundation, and the other four went over with the upper portion of the side barricade, and lay on the ground twenty feet from the barricade.

On the other side of the mill there was no barricade, and the debris was scattered over an area up to six hundred feet. Only three of the eight trunions on this side could be found, one a whole head and the other two broken

off clean to the hub, at distances of 425, 525 and 550 feet respectively.

As the ground was covered with snow over two feet deep, it was difficult to locate the missiles, and only those of considerable surface, could be found, such as pieces from the barrel shells and large heavy pieces of shafting.

The results of this explosion were studied with interest to note the effect of barricades. The fact that they deflected the air pressure upwards was very noticeable. The damage done to other buildings on the plant was remarkably light, consisting only of broken sash in the power house, four lights in a window of the corning mill, which also had its end wall slightly sprung, and the west wall of the press sprung a little. One large door on the pack house was drawn inward by the air current and damaged slightly. These are the only indications of concussion. Car sheds only 250 feet away show no evidence of concussion whatever. A small outhouse only 75 feet from the glaze and protected by the barricade shows no mark of a missile, and only one board was sprung.

The snow surrounding the three barricaded sides of the mill was covered with brands and debris but was soft and yielding, while to the west of the mill the snow for a distance of more than 200 feet was depressed to one-half its original depth, and so hard that it would bear a man's weight. There were no buildings on the unbarricaded side of the mill to measure possible damage in that direction.

Missiles were projected as far as 1750 feet to the east, and one missile was reported at a distance of 6600 feet. Part of a barrel head fell on a tram trestle near the wagon magazine, breaking the iron rail, cutting through a four by six tie and breaking two parallel timbers. Another piece of a barrel head, weighing 45 pounds, came down through the magazine roof, and struck the floor hard enough to make a hole through two floorings, covering the floor of an empty bin with splinters. About 19,000 kegs of powder were stored in this magazine at the time, and it was a fortunate circumstance that this missile hit an empty bin. This was 1175 feet from the glaze mill.

The barricades undoubtedly did deflect the air pressure upwards and avoided a large amount of damage to the surrounding mills. They confined a large part of the debris within their enclosure and reduced the number of missiles. Missiles thrown directly vertical were not checked by barricades, but were kept within a limited area.

Eye witnesses remarked that the debris went up into the air to a very great height, the missiles to be plainly seen falling in different directions, while the heavy black cloud, full of ground up timber, floated slowly to the southeast, leaving a black trail of pulverized wood on the snow, which could be traced across the lake to a distance of about a mile. This trail started at the site of the glazing mill and gradually widened out until it reached a width of 300 feet on the lake, making the snow black from the countless

particles of powdered blackened slivers of wood. In this trail were many heavy pieces of timber for a distance of 800 feet.

SUMMARY

Buildings damaged	Protection	Extent of damage	Feet distant from explosion
Power house	Barricaded	Sash broken	1250
Press house	Barricaded	Wall slightly bulged	1250
Area of structural damage.....			None to measure
Glass broken.....			1250 feet
Missiles thrown.....			6600 feet

